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Mechanisms of Innovation in Art–Science Collaboration: A Conceptual Framework for Responsible and Sustainable Development

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ABSTRACT: Art–Science collaboration has emerged as a significant interdisciplinary approach for addressing complex societal challenges, yet the mechanisms through which these partnerships drive responsible and sustainable innovation remain conceptually fragmented. This study develops an integrated conceptual framework explaining how Art–Science collaboration contributes to responsible innovation and sustainable development through collaborative knowledge production, drawing on a systematic literature review (2020–2026) of publications on Art–Science collaboration, SciArt, Research-Creation, Responsible Research and Innovation (RRI), and sustainability-focused interdisciplinary research, analyzed through narrative synthesis, thematic analysis, and evidence mapping. Seven interconnected mechanisms consistently characterize successful collaboration: problem reframing, imagination of alternative futures, public engagement, ethical anticipation, knowledge translation, material and technological experimentation, and cultural contextualization. Together, these mechanisms foster novel research questions, interdisciplinary knowledge integration, inclusive stakeholder participation, and reflexive governance. Effectiveness is maximized when artists function as epistemic partners throughout the research process rather than science communicators. Key enablers include boundary objects, co-design, shared governance, and long-term institutional support, while tokenism, power asymmetries, methodological fragmentation, and weak evaluation frameworks constrain transformative outcomes. The proposed framework integrates collaboration structures, innovation mechanisms, RRI principles, and six sustainability dimensions — cultural, social, environmental, technological, economic, and institutional. The study concludes that Art–Science collaboration should be reconceptualized as an innovation ecosystem, with responsible and sustainable innovation emerging through iterative, epistemologically diverse, ethically reflective, and participatory collaboration. The framework provides a foundation for future empirical validation, comparative research, and policy development.

Keywords: Art–Science Collaboration, Responsible Research and Innovation, Interdisciplinary Innovation, Sustainability, Knowledge Co-Production, Transdisciplinary Research, SciArt

INTRODUCTION

The increasing complexity of contemporary global challenges including climate change, biodiversity loss, public health crises, rapid technological transformation, and artificial intelligence

governance has exposed the limitations of conventional disciplinary approaches to scientific inquiry and innovation. These challenges are characterized by uncertainty, interconnected socio-ecological dynamics, and competing stakeholder interests, making them resistant to solutions derived solely from scientific or technological expertise. Consequently, researchers, policymakers, and cultural institutions have increasingly recognized the importance of interdisciplinary and transdisciplinary collaboration as a means of integrating diverse forms of knowledge into innovation processes. Within this context, Art–Science (SciArt) collaboration has emerged as an important field of inquiry that combines artistic creativity with scientific investigation to facilitate knowledge co-production, ethical reflection, public participation, and responsible innovation. Rather than positioning artistic practice merely as an aesthetic complement to scientific communication, recent scholarship increasingly conceptualizes artists as active contributors to research processes, capable of generating alternative perspectives, questioning dominant assumptions, and expanding the epistemological foundations of scientific knowledge (Connor et al., 2020; González-Zamar & Abad-Segura, 2021; Juhola, 2024).

Historically, the relationship between art and science has undergone a significant conceptual transformation. Earlier forms of collaboration primarily emphasized the communication of scientific knowledge through artistic media, where artworks functioned as tools for visualization, dissemination, and public engagement. Although these initiatives successfully broadened public awareness of scientific issues, they generally maintained clear disciplinary boundaries, with scientists producing knowledge and artists translating it for wider audiences. Contemporary literature, however, demonstrates a substantial shift from this communication-oriented paradigm toward collaborative models in which artists participate throughout the research lifecycle. This evolution reflects a transition from a deficit model of science communication to a framework of epistemic collaboration, where artistic and scientific practices jointly contribute to defining research questions, designing methodologies, interpreting evidence, and evaluating societal implications. Such developments signify that Art–Science collaboration is increasingly understood as a mechanism for producing new knowledge rather than simply communicating existing knowledge (Connor et al., 2020; Gerber, 2022; Juhola, 2024)j.

This conceptual shift is closely associated with broader developments in interdisciplinary and transdisciplinary research. Contemporary studies argue that complex sustainability challenges cannot be adequately addressed through isolated disciplinary expertise because they involve intertwined environmental, social, technological, political, and cultural dimensions. Accordingly, Art–Science collaboration is increasingly situated within transdisciplinary frameworks that encourage sustained cooperation among scientists, artists, policymakers, community organizations, and other societal actors. Rather than emphasizing temporary exchanges or isolated artistic interventions, recent scholarship advocates long-term, mission-oriented collaborations capable of integrating multiple knowledge systems into shared processes of inquiry and innovation. In marine conservation, climate adaptation, and environmental governance, for example, Art–Science collaborations have been shown to facilitate collective learning, stimulate dialogue among diverse stakeholders, and support place-based approaches to sustainability transitions through continuous co-creation rather than episodic communication activities (Carter et al., 2021; Jung et al., 2022; Matias et al., 2023).

An important consequence of this evolution is the reconceptualization of knowledge production itself. Increasingly, Art–Science collaboration is described as an epistemic partnership in which artists actively contribute to scientific understanding by introducing embodied experience, sensory perception, speculative imagination, and critical reflection into research processes. Connor et al. (2020) describe artists as epistemic partners, emphasizing that artistic inquiry can reshape scientific investigation by challenging assumptions, revealing overlooked perspectives, and generating alternative interpretations of complex phenomena. Rather than functioning solely as observers or communicators, artists embedded within laboratories, field studies, and research institutions participate directly in experimental design, methodological reflection, and interpretation of research findings. Studies of artist residencies and laboratory-based collaborations demonstrate that sustained interaction between artists and scientists facilitates mutual learning, encourages methodological innovation, and expands the range of questions that scientific research can address (Conte et al., 2024). These findings indicate that artistic practice contributes substantively to scientific knowledge production by introducing complementary modes of inquiry that enrich conventional empirical approaches.

The theoretical foundations explaining innovation in Art–Science collaboration similarly extend beyond traditional notions of creativity or interdisciplinary exchange. Innovation is increasingly understood as a process of knowledge integration occurring across disciplinary boundaries through continuous negotiation, experimentation, and reflexive learning. Gerber (2022), Arnal and Schuster-Wallace (2024), and Juhola (2024) argue that concepts such as boundary work and boundary objects provide useful analytical frameworks for explaining how heterogeneous communities collaborate despite differing epistemological assumptions and professional cultures. Boundary objects including prototypes, artistic installations, visual models, shared datasets, and collaborative workshops serve as mediating artifacts that facilitate communication and collective understanding among participants from diverse disciplinary backgrounds. Through these mechanisms, Art–Science collaboration enables participants to construct shared meanings while preserving disciplinary diversity, thereby fostering innovation that neither discipline could achieve independently.

Another influential perspective conceptualizes collaborative innovation through distinct institutional and epistemological logics. Szymanski et al. (2020) identify three complementary logics that shape Art–Science collaboration. The accountability logic emphasizes transparency, public communication, and the accessibility of scientific knowledge. The innovation logic focuses on creative problem solving, interdisciplinary experimentation, and the development of novel research approaches. In contrast, the ontology logic represents a deeper transformation by challenging disciplinary hierarchies and promoting equality among artistic and scientific ways of knowing. Together, these logics illustrate that successful Art–Science collaboration extends beyond generating creative outputs; it involves restructuring how knowledge is produced, evaluated, and applied in addressing complex societal challenges. Consequently, innovation within Art–Science collaborations should be understood not merely as technological advancement but as the emergence of new epistemic relationships capable of transforming research cultures, institutional practices, and societal engagement.

The increasing institutional recognition of Art–Science collaboration has also strengthened its relationship with the principles of Responsible Research and Innovation (RRI). RRI has emerged as a governance framework that promotes anticipation, reflexivity, inclusion, responsiveness, and ethical responsibility throughout the research and innovation process. Rather than evaluating scientific progress solely through technological or economic achievements, RRI emphasizes the alignment of innovation with societal values, public needs, and long-term sustainability. Within this framework, Art–Science collaboration is increasingly viewed as an effective mechanism for facilitating inclusive dialogue, expanding stakeholder participation, and encouraging critical reflection on the societal implications of emerging technologies. Artistic practices provide opportunities for exploring ethical dilemmas, visualizing uncertain futures, and stimulating public deliberation in ways that conventional scientific communication often cannot achieve (Fannin et al., 2020; Johansen, 2022).

Despite this conceptual alignment, the literature also highlights important tensions between Art–Science collaboration and RRI implementation. Several scholars caution that artistic participation should not become merely an instrumental strategy for enhancing public acceptance of scientific research or satisfying funding requirements. Johansen (2022) argues that reducing artistic practice to a communication or engagement tool risks undermining its critical and epistemic functions. Instead, successful Art–Science collaborations require an integrated framework in which artists, scientists, and social scientists contribute as equal partners throughout the research process. Such partnerships depend upon shared governance structures, openness to multiple epistemologies, and explicit recognition of the distinct contributions offered by each discipline. Likewise, Juhola (2024) and Safaa et al. (2023) emphasize that genuine interdisciplinary collaboration requires institutional arrangements that promote mutual respect, transparency, and equitable participation rather than symbolic inclusion. These observations reinforce the importance of epistemic equality as a prerequisite for responsible innovation and suggest that effective Art–Science collaboration should balance creativity, scientific rigor, and ethical responsibility without subordinating one domain to another.

Beyond governance considerations, recent literature demonstrates that artists increasingly occupy diverse and influential roles throughout scientific research itself. Rather than acting solely as science communicators or producers of visual representations, artists participate directly in framing research questions, challenging methodological assumptions, designing experiments, interpreting findings, and critically evaluating technological trajectories. The notion of artists as co-researchers or epistemic partners has therefore gained substantial attention within contemporary Art–Science scholarship. According to Connor et al. (2020) and Heinrichs (2021), artistic inquiry contributes unique forms of embodied, experiential, and critical knowledge that complement empirical scientific methods by revealing hidden assumptions, questioning dominant narratives, and expanding conceptual possibilities. Such contributions are particularly valuable when addressing complex societal problems that involve ethical uncertainty, cultural diversity, and competing stakeholder values.

Empirical evidence further demonstrates that artists embedded within laboratories, observatories, environmental research stations, and technological innovation centers frequently participate in

experimental workflows rather than remaining external observers. Laboratory residencies provide opportunities for sustained interaction in which artists observe scientific practice, contribute creative methodologies, and collaborate with researchers throughout the development of scientific investigations. Conte et al. (2024) report that these immersive collaborations encourage mutual learning, improve interdisciplinary communication, and stimulate methodological innovation by integrating artistic experimentation into scientific inquiry. Rather than producing isolated artistic outputs after research is completed, artists become active participants in generating scientific insights, developing alternative research strategies, and interpreting empirical evidence from multiple perspectives. Consequently, laboratory-based collaborations exemplify how Art–Science initiatives increasingly function as mechanisms of collaborative knowledge production rather than conventional outreach activities.

Another significant contribution of artists lies in their capacity to function as boundary spanners who facilitate communication across disciplinary cultures. Scientific disciplines often employ specialized terminologies, methodologies, and epistemological assumptions that create barriers to collaboration with other knowledge communities. Artistic practices, however, frequently generate boundary objects including visualizations, prototypes, installations, narratives, performances, and participatory workshops that enable participants from different backgrounds to negotiate shared meanings while maintaining disciplinary diversity. Gerber (2022) and Juhola (2024) argue that these boundary objects provide tangible platforms through which scientists, artists, policymakers, and community stakeholders collectively explore complex problems, exchange perspectives, and develop integrated solutions. Rather than simplifying disciplinary differences, boundary objects encourage productive dialogue that supports collaborative experimentation and innovation. Consequently, artists contribute not only creative outputs but also communication infrastructures that facilitate interdisciplinary integration and collective learning.

The governance dimension of Art–Science collaboration further illustrates the expanding responsibilities assumed by artists within innovation ecosystems. Emerging technologies including synthetic biology, artificial intelligence, biotechnology, and digital surveillance raise profound ethical, cultural, and societal questions that extend beyond technical feasibility. Within these contexts, artistic practices contribute to anticipatory governance by provoking reflection on potential risks, unintended consequences, and alternative futures before technologies become widely implemented. Through speculative design, bioart, immersive installations, and critical storytelling, artists encourage researchers and policymakers to consider issues of justice, inclusion, environmental sustainability, authorship, and social responsibility during early stages of technological development. Johansen (2022), Safaa et al. (2023), and Szymanski et al. (2020) argue that such anticipatory practices strengthen responsible innovation by broadening deliberation beyond technical expertise and incorporating diverse societal perspectives into governance processes.

The significance of Art–Science collaboration is particularly evident within sustainability research, where environmental challenges require integrated approaches capable of combining scientific evidence with cultural understanding and public engagement. Sustainability transitions involve not only technological innovation but also changes in values, behaviors, institutional structures, and

collective imagination. Consequently, many scholars now describe Art–Science collaboration as an epistemic partnership that supports sustainability by transforming how knowledge is produced, communicated, and applied. Rather than treating environmental problems exclusively as technical issues, collaborative initiatives encourage scientists, artists, local communities, policymakers, and civil society organizations to participate jointly in defining problems, generating evidence, interpreting findings, and developing context-sensitive responses. This collaborative model strengthens social legitimacy while expanding opportunities for innovation through diverse forms of expertise (Connor et al., 2020; Conte et al., 2024).

The growing recognition of Art–Science collaboration within sustainability research has also generated increasing interest among governments, funding agencies, and international organizations seeking new approaches to innovation policy. Rather than evaluating collaborative projects solely through technological outputs or economic performance, recent policy discourse emphasizes broader societal impacts, including social inclusion, cultural resilience, environmental stewardship, and institutional transformation. Art–Science initiatives are increasingly recognized as platforms for reflexive governance, responsible experimentation, and long-term stakeholder engagement that contribute to sustainability transitions beyond conventional research and development activities. Consequently, collaboration between artists and scientists is no longer viewed as an optional complement to scientific research but as an emerging strategy for fostering transformative innovation capable of addressing complex socio-ecological challenges (Johansen, 2022; Safaa et al., 2023).

Despite this growing body of scholarship, significant conceptual and methodological gaps remain. First, much of the existing literature consists of individual case studies documenting successful collaborations in specific disciplines or institutional contexts. Although these studies provide valuable empirical insights, they often emphasize project descriptions, artistic outputs, or public engagement activities without systematically explaining the underlying collaborative mechanisms responsible for generating innovation. Consequently, knowledge remains fragmented across environmental science, health research, engineering, digital technology, cultural studies, and artistic research, making it difficult to compare findings or develop cumulative theoretical understanding.

Second, previous reviews have generally focused on describing collaboration models such as Artist-in-Residence programs, embedded artists, research-creation initiatives, or museum–laboratory partnerships rather than examining the dynamic processes through which these models produce innovation. While collaborative structures are important, they do not fully explain why some initiatives generate transformative outcomes whereas others remain limited to communication or dissemination activities. The absence of an integrated analytical framework capable of linking collaborative processes, innovation mechanisms, responsible innovation principles, and sustainability outcomes represents a substantial limitation within current Art–Science scholarship. Without such a framework, researchers lack a consistent basis for comparing projects, evaluating effectiveness, and identifying transferable principles for future interdisciplinary initiatives.

Third, although Responsible Research and Innovation (RRI) provides valuable principles for inclusion, anticipation, reflexivity, and responsiveness, relatively few studies explicitly examine how these principles operate through concrete mechanisms within Art–Science collaborations. Existing discussions frequently acknowledge that artists contribute to ethical reflection, public dialogue, and participatory governance; however, the specific pathways through which artistic practices influence scientific decision-making, knowledge integration, and innovation remain insufficiently theorized. Likewise, concepts such as epistemic partnership, boundary work, and co-creation are often discussed independently rather than synthesized into a coherent conceptual model capable of explaining interdisciplinary innovation across diverse institutional settings.

These gaps indicate the need for a comprehensive synthesis that moves beyond descriptive accounts of collaborative projects toward a process-oriented understanding of innovation. Instead of asking whether Art–Science collaboration is beneficial, greater attention should be directed toward understanding how collaboration generates new knowledge, which mechanisms enable interdisciplinary innovation, and under what conditions these mechanisms contribute to responsible and sustainable development. Addressing these questions is particularly important as universities, research institutes, cultural organizations, and funding agencies increasingly invest in interdisciplinary initiatives intended to respond to global sustainability challenges. Developing a rigorous conceptual framework can therefore provide both theoretical clarity and practical guidance for designing, evaluating, and institutionalizing future Art–Science collaborations.

Accordingly, this study aims to develop an integrated conceptual framework explaining the mechanisms through which Art–Science collaboration contributes to responsible and sustainable innovation. Specifically, the study seeks to identify the principal innovation mechanisms reported across recent literature, examine how these mechanisms support knowledge integration and interdisciplinary collaboration, analyze their relationship with Responsible Research and Innovation principles, and synthesize their contributions to sustainable development. Rather than focusing on individual artistic outputs or isolated case studies, the review emphasizes collaborative processes including problem reframing, imagination and alternative futures, public engagement, ethical anticipation, knowledge translation, material and technological experimentation, and cultural contextualization as the primary drivers of innovation.

The novelty of this study lies in its integration of previously fragmented theoretical perspectives into a unified conceptual framework linking collaboration models, collaborative processes, innovation mechanisms, Responsible Research and Innovation, and sustainable development outcomes. While previous studies have examined individual aspects of Art–Science collaboration, few have synthesized these dimensions into a comprehensive explanatory model. By connecting interdisciplinary collaboration theory, boundary work, epistemic partnership, sustainability transitions, and RRI within a single analytical framework, this study contributes to a more systematic understanding of how Art–Science collaboration functions as an innovation ecosystem rather than merely a communication strategy. This integrated perspective provides a foundation for future empirical validation, comparative analysis across institutional contexts, and the development of evidence-based policies supporting interdisciplinary innovation.

The scope of this review is limited to literature published between 2020 and 2026 concerning Art–Science collaboration, SciArt, Research-Creation, Responsible Research and Innovation, and sustainable innovation. The analysis focuses on identifying recurring innovation mechanisms across diverse disciplinary contexts rather than evaluating the effectiveness of individual projects. Through a systematic synthesis of contemporary scholarship, this study seeks to advance theoretical understanding of Art–Science collaboration while offering practical implications for researchers, cultural institutions, policymakers, and funding organizations seeking to strengthen interdisciplinary approaches to responsible and sustainable development.

METHOD

Research Design

This study employed a systematic literature review combined with narrative synthesis, thematic analysis, and evidence mapping to examine the mechanisms through which Art–Science collaboration contributes to responsible and sustainable innovation. This design was selected because the field is characterized by conceptual diversity, methodological heterogeneity, and substantial variation in institutional, disciplinary, and cultural contexts. Existing studies encompass qualitative case research, ethnographic inquiry, participatory design, systematic reviews, bibliometric analysis, mixed-method evaluation, and transdisciplinary research. A synthesis-oriented methodology was therefore required to integrate findings across these distinct approaches without assuming that all evidence could be standardized or statistically aggregated.

Qualitative case studies and ethnographic-style inquiries are among the most common methods used to investigate Art–Science collaboration. These approaches are particularly appropriate for examining collaborative practices, stakeholder experiences, epistemic negotiations, and institutional conditions within laboratories, field sites, exhibitions, educational settings, and public engagement programs (Birsel et al., 2022; Johansen, 2022). Interpretive designs also allow researchers to identify how boundary work, co-creation, role negotiation, and knowledge integration develop over time (Birsel et al., 2022). However, because these studies are often context-specific, the present review used comparative thematic synthesis to identify recurring mechanisms across cases while retaining sensitivity to institutional and disciplinary differences.

Systematic reviews, scoping reviews, and bibliometric mappings have also been widely used to examine STEAM integration, arts-based sustainability research, transdisciplinary education, and related forms of Art–Science collaboration (Mejias et al., 2021; Rodier et al., 2021). Building on these methodological precedents, the present study adopted a structured review protocol to identify, screen, classify, and synthesize relevant literature.

Review Scope and Research Questions

The review focused on studies addressing Art–Science collaboration, SciArt, Research-Creation, STEAM-related interdisciplinary practice, responsible innovation, transdisciplinary sustainability research, and artistic participation in scientific inquiry. The analysis was guided by three methodological questions:

1. Which research designs are most commonly used to investigate Art–Science collaboration?
2. How are collaboration processes measured and evaluated in interdisciplinary innovation studies?
3. Which variables are most frequently extracted in systematic reviews of Art–Science collaboration?

These questions supported the development of a transparent extraction framework while also identifying methodological strengths, limitations, and inconsistencies within the field.

Search Strategy and Information Sources

The literature search was designed to retrieve peer-reviewed articles, review papers, empirical case studies, practice-based research, and relevant institutional reports. Searches were conducted across major academic databases and scholarly discovery platforms, including Scopus, Web of Science, Dimensions, and Google Scholar. Additional institutional sources were considered where they provided substantial evidence concerning responsible innovation, sustainability governance, transdisciplinary research, or Art–Science policy.

Search strings combined terms related to collaboration, artistic practice, scientific inquiry, innovation, and sustainability. Representative combinations included "Art–Science collaboration," "SciArt," "research-creation," "artist-in-residence," "embedded artist," "STEAM," "transdisciplinary innovation," "responsible research and innovation," "boundary work," "co-design," "public engagement," and "sustainability transitions." Boolean operators were used to connect these concepts and improve retrieval precision.

The review concentrated primarily on literature published between 2020 and 2026 because this period captures recent developments in Art–Science collaboration, responsible innovation, sustainability transitions, and institutional experimentation. Earlier sources were retained only when they provided essential theoretical or methodological foundations.

Eligibility Criteria

Studies were included when they met at least one of the following conditions: they examined collaboration between artistic and scientific disciplines; analyzed interdisciplinary or transdisciplinary innovation involving arts-based methods; evaluated Art–Science processes,

outcomes, or governance; investigated artists working in laboratories, field sites, educational programs, museums, or public engagement initiatives; or addressed responsible innovation, sustainability, and co-creation through artistic–scientific integration.

Empirical qualitative, quantitative, and mixed-method studies were eligible, as were systematic reviews, scoping reviews, bibliometric analyses, conceptual papers, and institutional reports. Studies were excluded when art was used only as a decorative or communication device without meaningful interaction with scientific inquiry, when the collaboration process was insufficiently described, or when the publication lacked sufficient information to determine methods, context, or outcomes.

Because the field spans education, sustainability science, public health, museum practice, technology, and environmental research, methodological heterogeneity was expected. Rather than excluding studies solely because of design differences, the review classified them according to methodological type and analytical contribution.

Study Selection Procedure

The selection process involved four stages: identification, screening, eligibility assessment, and final inclusion. First, records were identified through database and institutional searches. Second, titles and abstracts were screened to remove duplicate or clearly irrelevant publications. Third, full texts were evaluated against the eligibility criteria. Finally, eligible studies were included in the evidence matrix and coded according to the extraction framework.

The screening process gave particular attention to whether each publication described collaboration mechanisms, stakeholder roles, research design, analytical procedures, institutional context, and innovation outcomes. Studies that used broad terms such as interdisciplinarity or STEAM were included only when artistic and scientific practices were substantively connected.

Data Extraction Framework

Data extraction was organized into six principal categories. The first category recorded bibliographic and study characteristics, including author, year, country, title, journal or institution, research design, project duration, and funding source. The second category captured disciplinary and institutional context, including the art discipline, science discipline, organizational setting, geographic location, and sector.

The third category documented collaboration characteristics. Extracted variables included project initiation, collaboration level, decision-making structure, community involvement, knowledge-exchange direction, intellectual ownership, and governance arrangements. Specific collaboration mechanisms such as co-design, artist residencies, lab-embedded practices, workshops, public

engagement, boundary objects, and boundary-spanning roles were also recorded (Butt & Dimitrijević, 2022; Júnior, 2023).

The fourth category recorded methodological characteristics, including research design, data sources, sampling strategy, data-collection methods, and analytical techniques. Commonly extracted methods included interviews, focus groups, participant observation, ethnographic field notes, artifacts, project documentation, thematic coding, framework analysis, bibliometrics, and social-network analysis (Harris & Carter, 2021; Meletiou-Mavrotheris et al., 2022).

The fifth category captured outcomes and impacts, including cognitive learning, affective change, creativity, engagement, audience response, attitudinal shifts, behavior change, policy influence, and institutional transformation (Carter et al., 2021; Heras et al., 2021). The sixth category recorded theoretical frameworks, including boundary work, co-production, Responsible Research and Innovation, STEAM theory, post-normal science, sustainability science, and helix-based innovation models (Juhola, 2024).

Coding and Thematic Analysis

The extracted material was analyzed through iterative thematic coding. Initial codes were derived deductively from the research questions and extraction framework. These included collaboration structure, epistemic role, boundary object, co-design, public engagement, governance, reflexivity, innovation output, sustainability outcome, and evaluation method. Additional codes were developed inductively when recurring concepts emerged from the literature.

The coding process focused on identifying mechanisms rather than merely cataloguing project types. Particular attention was given to how collaborations reframed problems, developed shared languages, negotiated roles, generated experimental practices, included stakeholders, addressed ethical concerns, and translated knowledge across disciplinary and public boundaries.

Evaluation of Collaboration Processes

Collaboration was treated as a dynamic process rather than a static institutional arrangement. Evaluation therefore considered how interactions evolved over time, how responsibilities were distributed, and whether different epistemologies were meaningfully integrated. Process-focused approaches included reflexive monitoring, governance analysis, boundary-work assessment, and examination of co-creation quality (Gerber, 2022).

Boundary objects and boundary-spanning roles were coded as indicators of cross-disciplinary coordination. Evaluation considered whether shared artifacts, models, workshops, or prototypes improved mutual understanding and whether authority was distributed equitably. Social-learning and governance indicators included stakeholder inclusion, responsiveness, anticipation, reflexivity, and ethical deliberation (Johansen, 2022).

Where available, bibliometric and social-network measures were recorded to assess collaboration density, disciplinary connectivity, dissemination pathways, and temporal development (Pineo et al., 2021). Outcome assessment also included cognitive, affective, behavioral, institutional, and policy effects. However, the review recognized persistent attribution problems and the limited availability of longitudinal evidence (Heras et al., 2021).

Evidence Synthesis

Because the reviewed studies differed substantially in design, indicators, sample size, and outcome measurement, statistical meta-analysis was not considered appropriate. Instead, the study used narrative synthesis and mixed-method evidence mapping. Findings were compared across collaboration types, methodological designs, innovation mechanisms, and sustainability dimensions.

The synthesis also examined tensions within the literature. Some studies present RRI and governance frameworks as enabling conditions for co-creation, whereas others warn that such frameworks may instrumentalize art or reduce artistic participation to policy compliance (Kelly et al., 2023). These disagreements were retained as analytically relevant rather than resolved through simple aggregation.

Methodological Quality and Limitations

Methodological quality was assessed through transparency of research design, clarity of data collection and analysis, adequacy of contextual description, evidence supporting conclusions, and acknowledgment of limitations. For review studies, attention was given to search transparency, eligibility criteria, and coding procedures. For empirical studies, emphasis was placed on sampling logic, triangulation, reflexivity, and the relationship between evidence and interpretation.

The principal limitation of the review is the heterogeneity of the field. Art–Science collaboration encompasses education, sustainability, public health, technological development, museums, climate communication, and community practice. Consequently, variables and outcome measures are not fully standardized. A second limitation is the predominance of qualitative and short-term case studies, which restricts causal inference and long-term impact assessment. Nevertheless, preserving contextual variation while applying a common analytical framework enables the study to identify recurring mechanisms and develop a theoretically grounded model of Art–Science innovation.

RESULT AND DISCUSSION

Reframing Scientific Problems through Artistic Practice

The reviewed literature consistently indicates that artistic practice reshapes scientific problem framing by introducing embodied, sensory, narrative, and reflexive modes of inquiry. These modes broaden the range of assumptions, experiences, and values considered during the formulation of scientific problems. Rather than accepting established definitions as fixed, artists frequently question how a problem has been constituted, whose perspectives are represented, and which dimensions have been excluded. This contribution is especially visible in collaborations where artists work as epistemic partners rather than as external communicators of completed research (Connor et al., 2020; Szymanski et al., 2020; Birsel et al., 2022).

Artistic reframing commonly occurs through sustained immersion in laboratories, field sites, residencies, and collaborative design settings. In these contexts, artists observe research practices, engage with experimental routines, and examine the conceptual assumptions underlying scientific questions. Such participation allows artistic inquiry to influence not only how research is represented but also how its objectives, methods, and interpretive boundaries are defined (Conte et al., 2024; Birsel et al., 2022). This suggests that the principal contribution of artistic involvement lies in its capacity to alter the research trajectory before findings are produced.

The evidence further shows that artists contribute to generating new scientific questions by operating as co-researchers. Their embodied and critical approaches enable them to identify blind spots that may remain invisible within established disciplinary frameworks. Artists who shadow laboratory work, participate in experimentation, or contribute to the interpretation of data can prompt questions concerning perception, representation, uncertainty, causality, and meaning that conventional research routines might not foreground (Heinrichs, 2021; Birsel et al., 2022). In this sense, artistic practice does not merely supplement scientific reasoning; it expands the epistemic field within which scientific questions become possible.

Boundary-work and boundary-object theories provide an important explanation of this process. Shared artifacts such as prototypes, installations, diagrams, models, datasets, and collaborative workshops help participants from different professional cultures negotiate meanings and clarify assumptions. These objects make emerging questions visible and discussable across disciplinary boundaries, thereby facilitating changes in problem scope and analytical orientation (Gerber, 2022; Juhola, 2024; Júnior, 2023). The resulting innovation may take the form of new experimental designs, new conceptual categories, or new relationships among scientific, cultural, and social dimensions of a problem.

Evidence from ocean, climate, and sustainability-oriented collaborations indicates that reframing can also influence broader research missions. In these settings, artistic involvement has helped transform narrowly technical problems into transdisciplinary questions concerning ecological relationships, public values, cultural meaning, and long-term societal change. Such reframing supports boundary-spanning inquiry and may redirect research toward more context-sensitive and sustainability-oriented trajectories (Arnal & Schuster-Wallace, 2024).

Several theoretical models converge in explaining collaborative problem framing. Boundary-work theory emphasizes negotiation across professional cultures, whereas Responsible Research and Innovation highlights anticipation, reflexivity, inclusion, and societal desirability (Johansen, 2022; Szymanski et al., 2020; Heras et al., 2021). Transdisciplinary and Mode-4 knowledge-production perspectives further situate reframing within iterative, multi-actor, and co-designed processes that integrate scientific, artistic, educational, and societal knowledge (Ertas, 2022; Moleka, 2024). Collectively, these frameworks show that problem reframing is not an incidental creative effect but a central mechanism through which Art–Science collaboration generates innovation.

Imagination and the Construction of Alternative Futures

The second major mechanism identified in the literature is the use of imagination to construct alternative futures. Speculative design, scenario building, artistic prototyping, narrative futures, and immersive experiences provide spaces in which uncertain technological, social, and environmental developments can be explored before they are fully realized. These methods expand the range of possible outcomes considered in research and policy, thereby challenging assumptions that current technological or institutional trajectories are inevitable (Szymanski et al., 2020; Heras et al., 2021; Fannin et al., 2020; Mogles et al., 2020).

Speculative approaches contribute to innovation by translating abstract risks and possibilities into tangible situations. Through objects, performances, installations, or narratives, artists can render future consequences perceptible and open them to critical discussion. This process supports the reformulation of current research priorities by connecting technical developments with questions of social desirability, justice, ethics, and long-term sustainability. Instead of forecasting a single future, artistic speculation enables participants to compare multiple scenarios and consider how present decisions may create divergent outcomes.

In climate and ocean research, imaginative methods have been used to support horizon scanning and mission-oriented inquiry. These collaborations link scientific evidence with culturally meaningful representations of ecological change, allowing researchers and stakeholders to consider adaptation, stewardship, and resilience through experiential and narrative forms (Jung et al., 2022; Matias et al., 2023). Such work suggests that imagination contributes to innovation not by replacing empirical analysis but by broadening the interpretive and normative contexts in which evidence is evaluated.

The reviewed studies also identify imagination as a cognitive and collaborative resource. It supports the redescription of phenomena, tolerance of ambiguity, and generation of novel methods and visual forms. Artists and scientists may use imaginative practices to develop alternative representations, question conventional classifications, and explore relationships that are difficult to capture through disciplinary methods alone (Connor et al., 2020; Heinrichs, 2021; Heras et al., 2021; Birsel et al., 2022). This function is particularly evident in STEAM and transdisciplinary education, where imagination is linked to creativity, integrative thinking, and the development of new epistemic practices (Mejias et al., 2021; Rodier et al., 2021; Moleka, 2024; Meletiou-Mavrotheris et al., 2022).

Immersive and participatory experiences represent a further manifestation of future-oriented imagination. Exhibitions, performances, interactive installations, citizen-science laboratories, and co-creative environments allow participants to encounter possible sustainability futures through sensory and situated experience. Such formats can help publics and practitioners engage with complex social-ecological systems, explore policy implications, and reflect on the consequences of alternative choices (Matias et al., 2023; Arnal & Schuster-Wallace, 2024).

The evidence suggests that these experiences can support learning, broaden participation, and contribute to the co-design of sustainability interventions, including nature-based and place-based solutions (Tkach et al., 2023). However, explicit causal evidence linking immersive artistic experiences to long-term sustainability outcomes remains limited. Most studies report changes in engagement, interpretation, or collaborative capacity rather than verified long-term behavioral or institutional transformation.

Artistic imagination is also closely associated with responsible innovation. Studies framed through RRI show that imaginative inquiry can reveal questions of accountability, inclusion, risk, and social desirability that might otherwise enter the innovation process too late (Juhola, 2024; Heras et al., 2021). Transdisciplinary laboratories and SciArt initiatives similarly demonstrate that speculative practice can support reflexive governance and horizon scanning. Nevertheless, the literature cautions that such practices may become instrumentalized when they are used primarily to legitimize predefined technological agendas or satisfy engagement requirements (Parodi et al., 2022).

Public Engagement and Participatory Innovation

The third mechanism concerns the role of Art–Science collaboration in public engagement. The evidence indicates that exhibitions, performances, digital narratives, interactive installations, and participatory workshops can make scientific processes more accessible and relatable. These formats humanize researchers, foreground the uncertainties and iterative nature of scientific work, and translate technical content into forms that are easier for diverse audiences to interpret (Ruvolo et al., 2022).

Collaborative exhibition models are particularly effective when artists and scientists jointly construct the narrative rather than when artists are asked to visualize completed findings. Co-created exhibitions can show how knowledge was produced, why particular questions matter, and where uncertainty remains. This can strengthen public understanding by shifting attention from isolated facts to the research process itself. Immersive exhibit design, scrollytelling, and interactive digital presentation have also been identified as useful approaches for sustaining attention and improving comprehension of complex topics (Scotti, 2020).

Storytelling is repeatedly identified as a central engagement mechanism. Scientific information becomes more meaningful when presented through narrative structures that include context, sequence, conflict, consequence, and human experience. Stories can generate emotional resonance and improve recall while helping audiences situate scientific evidence within social and ethical contexts (Fakunle et al., 2021; Oliver, 2024). Digital storytelling and scrollytelling further extend

these functions by combining text, image, movement, sound, and interactive data to communicate complex subjects to heterogeneous publics (Seidel et al., 2023).

Citizen science represents a more participatory form of engagement. In Art–Science settings, citizen-science approaches can connect data collection with creative practice, enabling participants to contribute observations, interpretations, and locally grounded knowledge. These hybrid models can widen participation, mobilize lay expertise, and support the co-production of evidence relevant to both scientific research and public decision-making (Krebs et al., 2024).

The reported outcomes include learning, increased engagement, new forms of awareness, and potential changes in attitudes or behavioral intentions. However, systematic evidence of long-term behavioral impact remains uneven. The literature therefore recommends mixed-method and longitudinal evaluation designs capable of capturing cognitive, affective, behavioral, institutional, and policy-related effects (Heras et al., 2021; Parodi et al., 2022).

Public participation also influences innovation by shaping research priorities and revealing needs that may be overlooked by expert-led processes. Participatory design, co-learning, and collaborative workshops allow stakeholders to define problems, assess possible solutions, and contribute to the production of shared knowledge artifacts (Heras et al., 2021; Butt & Dimitrijević, 2022). These practices can increase the relevance and legitimacy of research outcomes because participants are involved in determining both the questions and the criteria of success.

Nevertheless, participation does not automatically produce equitable collaboration. The literature repeatedly notes risks of tokenism, uneven authority, selective representation, and the appearance of inclusion without meaningful influence. Governance arrangements that distribute decision-making power, recognize diverse epistemologies, and support reflexive monitoring are therefore necessary if public participation is to contribute to responsible innovation rather than merely validate predetermined agendas (Johansen, 2022; Juhola, 2024; Szymanski et al., 2020; Júnior, 2023).

Ethical Anticipation and Responsible Governance

The fourth mechanism identified is ethical anticipation. Within Art–Science collaboration, ethical anticipation refers to the deliberate examination of possible risks, benefits, exclusions, and unintended consequences throughout the research and innovation process. RRI and related anticipatory governance frameworks provide the principal conceptual basis for this mechanism. They encourage researchers and stakeholders to consider social desirability, uncertainty, responsibility, and responsiveness before technologies or interventions become stabilized (Johansen, 2022; Szymanski et al., 2020; Heras et al., 2021; Parodi et al., 2022).

Art–Science collaboration supports anticipation by creating spaces for reflexive questioning. Artistic methods can make abstract ethical issues perceptible through speculative scenarios, embodied encounters, provocative objects, or alternative narratives. These practices invite participants to consider who may benefit, who may be excluded, how risks are distributed, and which values are embedded in technological choices. Real-world laboratories, reflexive

sustainability labs, and integrated technology-assessment models provide organizational settings in which such questioning can be incorporated into continuing research cycles (Parodi et al., 2022; Mogles et al., 2020).

The literature also identifies several ethical challenges internal to Art–Science collaboration. Instrumentalization occurs when artistic practice is used primarily to promote science, satisfy funding requirements, or generate public acceptance. Tokenism arises when artists or communities are included symbolically but lack influence over research decisions. Power asymmetries may privilege scientific authority, institutional priorities, or policy objectives over artistic epistemologies and community knowledge (Juhola, 2024; Szymanski et al., 2020).

Additional concerns involve consent, safety, authorship, intellectual ownership, and risk assessment. These issues are especially significant when artists participate in embodied laboratory work, biological experimentation, or open-ended technological exploration. Conventional ethical review procedures may not adequately address the iterative and co-created character of such projects, creating a need for adaptable governance mechanisms that recognize interdisciplinary uncertainty and shared responsibility (Szymanski et al., 2020; Heinrichs, 2021).

Artistic practice contributes to responsible innovation by broadening the range of questions considered legitimate within research. It foregrounds ethical reflection, societal desirability, and alternative forms of evidence, thereby challenging innovation models focused narrowly on technical performance or economic value (Szymanski et al., 2020; Heras et al., 2021; Fannin et al., 2020). Yet this contribution depends on whether artists have substantive influence over problem framing, experimentation, interpretation, and governance. Without such influence, artistic participation risks becoming a public-relations or compliance function (Johansen, 2022; Juhola, 2024).

The governance frameworks most strongly supported by the literature are RRI, reflexive governance, real-world laboratory models, co-design, and boundary-work-informed coordination. These approaches emphasize transparency, inclusive decision-making, shared accountability, ongoing assessment, and responsiveness to emerging concerns (Johansen, 2022; Parodi et al., 2022; Mogles et al., 2020; Kelly et al., 2023). Boundary-work perspectives additionally clarify how responsibilities and standards can be negotiated across disciplines without erasing epistemic differences (Gerber, 2022; Júnior, 2023).

Taken together, the findings from Sections 3.1–3.4 show that Art–Science collaboration contributes to innovation through four interconnected mechanisms: reframing established problems, imagining alternative futures, expanding public participation, and anticipating ethical consequences. These mechanisms are mutually reinforcing. Reframing broadens the problem space, imagination expands the range of possible responses, participation introduces societal knowledge, and ethical anticipation guides innovation toward more responsible outcomes. The evidence therefore supports a process-oriented interpretation of Art–Science innovation in which collaborative quality, epistemic equality, and governance conditions are as important as the final artistic or scientific outputs.

The findings indicate that innovation in Art–Science collaboration is best understood as a relational and process-based phenomenon rather than as the direct result of combining artistic and scientific outputs. The mechanisms identified in this study problem reframing, imagination, public participation, ethical anticipation, knowledge translation, and collaborative experimentation closely align with established theories of interdisciplinary innovation, particularly boundary-work, boundary-object, co-production, and transdisciplinary knowledge-creation frameworks. Boundary-work theory explains how participants negotiate differences in language, authority, method, and epistemic legitimacy, while boundary objects provide shared points of reference through which heterogeneous actors can coordinate without eliminating disciplinary diversity (Gerber, 2022; Júnior, 2023; Juhola, 2024). In Art–Science collaboration, prototypes, installations, narratives, datasets, visualizations, and workshops frequently perform this mediating function. They do not merely communicate established findings but support the development of shared meanings, revised questions, and new forms of inquiry.

These results also correspond with contemporary models of co-production and transdisciplinary innovation, which reject linear assumptions that knowledge moves from experts to users in a one-directional sequence. Instead, knowledge is generated iteratively through interactions among researchers, practitioners, institutions, communities, and publics. This interpretation is consistent with Mode-4 knowledge production and broader helix-based models that expand innovation beyond universities and industry to include civil society, cultural actors, and other social stakeholders (Mejias et al., 2021; Moleka, 2024; Meletiou-Mavrotheris et al., 2022; Pineo et al., 2021). The Art–Science field extends these models by demonstrating that artistic knowledge contributes not only creativity or representation but also embodied, interpretive, affective, and critical forms of understanding. These contributions broaden the epistemic basis of collaboration by questioning what counts as valid evidence, legitimate method, and meaningful innovation (Connor et al., 2020; Heinrichs, 2021; Birsel et al., 2022; Júnior, 2023).

Responsible Research and Innovation provides an additional interpretive framework for the findings. The mechanisms of public engagement, ethical anticipation, and reflexive problem framing correspond directly with the RRI principles of inclusion, anticipation, responsiveness, and reflexivity. Art–Science collaboration can therefore function as a governance-oriented mode of innovation in which technological and scientific possibilities are assessed in relation to societal values, cultural contexts, and long-term consequences (Johansen, 2022; Szymanski et al., 2020; Heras et al., 2021; Parodi et al., 2022). However, this alignment should not be interpreted uncritically. The same literature that presents RRI as an enabling framework also warns that policy-oriented collaboration may instrumentalize art by treating it as a tool for public acceptance, institutional legitimacy, or compliance. Responsible collaboration therefore depends on whether artists possess substantive influence over research questions, methods, interpretation, and governance rather than being involved only in dissemination.

Institutional conditions strongly shape whether these innovation mechanisms can operate effectively. Shared governance, equitable decision-making, and formal recognition of artistic epistemic contributions are consistently associated with stronger collaborative outcomes (Johansen, 2022; Szymanski et al., 2020; Júnior, 2023). Institutions must provide structures through which responsibilities, authorship, compensation, intellectual ownership, and ethical accountability

can be negotiated transparently. Without such arrangements, apparently collaborative projects may reproduce disciplinary hierarchies in which scientific institutions retain control over agendas, resources, and definitions of success.

Long-term structural commitment is equally important. Sustained, place-based, and mission-oriented initiatives provide time for collaborators to develop trust, shared language, and mutual methodological understanding. Evidence from ocean research, climate initiatives, urban sustainability laboratories, and public-health collaborations suggests that durable institutional platforms are more capable of producing transdisciplinary learning and transformative outcomes than short-term, event-based projects (Edmonds et al., 2021; Mogles et al., 2020). Funding arrangements should therefore support experimentation, iteration, documentation, and reflexive evaluation rather than reward only immediately measurable products. Nevertheless, funding and policy alignment can create pressure to produce predefined narratives or visible outputs. Preserving artistic autonomy and methodological plurality is therefore essential to prevent collaboration from becoming instrumental or performative (Fannin et al., 2020; Parodi et al., 2022).

Educational ecosystems also influence institutional capacity. Graduate programs, STEAM initiatives, and transdisciplinary curricula can cultivate boundary-spanning competencies, co-design skills, reflexive practice, and the ability to work across epistemological differences (Liu & Tran, 2022; Mogles et al., 2020). Such capacities are not incidental. They form part of the infrastructure required for sustained Art–Science innovation because collaboration depends on participants who can negotiate uncertainty, disciplinary language, and competing evaluative standards.

Several barriers continue to limit responsible and sustainable outcomes. Instrumentalization and tokenism remain among the most persistent risks. Art may be treated as decorative, communicative, or politically useful without being granted epistemic authority (Johansen, 2022; Juhola, 2024; Szymanski et al., 2020; Fannin et al., 2020). Power asymmetries also affect recognition, compensation, decision rights, and ownership, weakening trust and co-ownership (Júnior, 2023). Furthermore, the effects of Art–Science projects are difficult to attribute because outcomes are often diffuse, delayed, and multidimensional. Existing studies frequently demonstrate changes in engagement, interpretation, or collaborative capacity but provide less evidence of long-term behavioral, policy, institutional, or ecological transformation (Liu et al., 2024; Parodi et al., 2022).

Ethico-legal concerns add further complexity. Co-created laboratory practices may involve safety, consent, biological materials, authorship, intellectual property, and forms of experimentation that do not fit conventional research-review procedures (Heinrichs, 2021; Kelly et al., 2023). Contextual heterogeneity presents another challenge. Art–Science collaboration spans education, public engagement, climate science, public health, sustainability governance, and technological innovation, producing substantial variation in aims, methods, and indicators (Butt & Dimitrijević, 2022; Wallen et al., 2022). Universal evaluation criteria may therefore obscure important differences, yet complete methodological fragmentation prevents comparison.

Future research should address these limitations through longitudinal and cross-context studies that follow collaborations beyond project completion and examine the durability, diffusion, and

institutionalization of outcomes (Mogles et al., 2020; Edmonds et al., 2021). Standardized but adaptable evaluation frameworks are also needed to capture cognitive, affective, behavioral, organizational, policy, and sustainability effects through mixed qualitative and quantitative methods (Júnior, 2023; Parodi et al., 2022). Finally, empirical research should test the causal pathways proposed in this study by examining how boundary objects, co-design, governance, and epistemic equality influence the generation of research questions, methods, artifacts, and institutional change. Such work would enable the field to move from persuasive case narratives toward stronger comparative explanations of how Art–Science collaboration produces responsible and sustainable innovation.

CONCLUSION

This study examined the mechanisms through which Art–Science collaboration contributes to responsible and sustainable innovation. The findings show that the value of Art–Science collaboration does not lie solely in the production of artworks, exhibitions, or communication outputs. Its principal contribution emerges from the collaborative processes that reshape research questions, expand imaginative possibilities, strengthen public participation, anticipate ethical consequences, and integrate scientific, artistic, and societal forms of knowledge.

Four interrelated mechanisms were particularly significant. First, artistic practice contributes to problem reframing by questioning disciplinary assumptions and introducing embodied, sensory, cultural, and narrative perspectives into scientific inquiry. Second, speculative and imaginative methods broaden the range of possible futures considered in research and policy, helping participants explore uncertainty, social desirability, and long-term consequences. Third, exhibitions, storytelling, citizen science, and participatory design expand public engagement and allow communities to influence research priorities and interpretations. Fourth, ethical anticipation encourages researchers and institutions to consider risks, exclusions, power relations, and unintended outcomes throughout the innovation process.

The analysis further demonstrates that these mechanisms are most effective when Art–Science collaboration is organized as an epistemic partnership. Shared governance, equitable decision-making, sustained interaction, and recognition of artistic knowledge are essential conditions for meaningful co-creation. Boundary objects, such as prototypes, installations, datasets, visualizations, and workshops, facilitate communication across disciplinary cultures and support the integration of different methods and forms of evidence. In this respect, Art–Science collaboration extends conventional interdisciplinary innovation by incorporating experiential, affective, interpretive, and critical forms of knowledge into research and governance.

The main contribution of this study is the development of a process-oriented conceptual framework linking collaboration structures, innovation mechanisms, responsible research practices, and sustainability outcomes. The framework explains why some initiatives progress from short-term communication toward transdisciplinary innovation and institutional transformation, whereas others remain limited to symbolic participation or dissemination. It also positions

Responsible Research and Innovation as a valuable governance framework while emphasizing that its benefits depend on the protection of artistic autonomy, epistemic equality, and genuine stakeholder influence.

The findings have practical implications for universities, laboratories, cultural institutions, funding agencies, and policymakers. Successful initiatives require long-term funding, flexible evaluation criteria, interdisciplinary staff, transparent agreements concerning authorship and intellectual ownership, and institutional structures capable of supporting experimentation and uncertainty. Evaluation should move beyond conventional output counts and include cognitive, affective, social, institutional, policy, and environmental effects. Particular attention must also be given to power asymmetries, tokenism, cultural appropriation, safety, consent, and the risk of using art merely to legitimize predefined scientific or political agendas.

Future research should test the proposed framework through longitudinal and comparative studies across different disciplinary, institutional, and cultural contexts. Mixed-method designs are needed to examine causal relationships between collaboration quality, specific innovation mechanisms, and long-term outcomes. Further studies should also develop standardized yet context-sensitive indicators for evaluating knowledge integration, public participation, institutional change, policy uptake, behavioral effects, and sustainability impacts. Greater attention should be directed toward governance models, compensation, decision rights, community ownership, and the durability of collaborations after external funding ends.

Overall, Art–Science collaboration should be understood as an innovation ecosystem rather than a supplementary communication activity. When supported by epistemic equality, reflexive governance, sustained co-creation, and institutional commitment, it can generate new research questions, more inclusive forms of knowledge production, responsible technological development, and culturally grounded pathways toward sustainability.

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