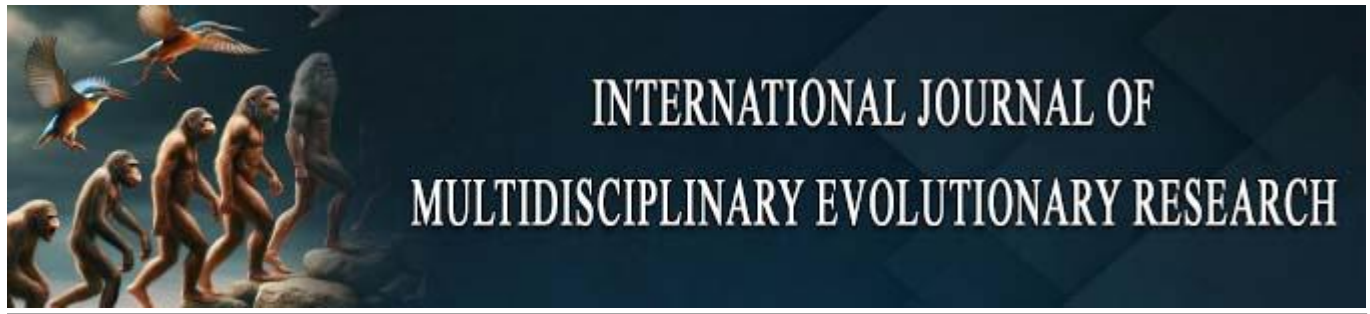




Integrative Approaches in Multidisciplinary Research: Bridging Science, Technology, and Society

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Article Info

P-ISSN: 3051-3502

E-ISSN: 3051-3510

Volume: 06

Issue: 02

July - December 2025

Received: 12-07-2025

Accepted: 15-08-2025

Published: 16-09-2025

Page No: 29-34

Abstract

Background: The increasing complexity of contemporary challenges requires research approaches that effectively integrate scientific knowledge, technological innovation, and societal needs. Integrative multidisciplinary research has emerged as a critical framework for bridging these domains through systematic methodological approaches.

Objective: This study examines integrative approaches in multidisciplinary research, analyzing frameworks, methodologies, and applications that successfully connect science, technology, and society to address complex real-world problems.

Methods: A comprehensive literature review was conducted examining integrative research methodologies, Science-Technology-Society frameworks, sociotechnical systems approaches, and transdisciplinary case studies. Sources included peer-reviewed articles, methodological papers, case studies, and institutional reports spanning 2003-2025.

Results: Key integrative approaches include Science-Technology-Society (STS) integration, sociotechnical systems design, transdisciplinary case studies, integrative mixed methods, and knowledge co-production. Successful applications demonstrate effectiveness in social innovation, sustainable technology development, and community-based solutions. However, challenges persist including methodological complexity, institutional barriers, and coordination difficulties.

Conclusion: Integrative multidisciplinary research provides essential frameworks for bridging science, technology, and society, generating transformative outcomes through systematic integration of diverse knowledge domains. Success requires continued development of methodological frameworks and institutional support structures.

Keywords: integrative research, multidisciplinary collaboration, science-technology-society, sociotechnical systems, transdisciplinary methods, knowledge co-production

Introduction

The modern research environment is characterized by increasing recognition that the most pressing challenges facing society require approaches that transcend traditional disciplinary boundaries and effectively integrate scientific knowledge, technological innovation, and social understanding. From climate change and digital transformation to public health and sustainable development, contemporary problems demand research frameworks that can bridge the gap between technical expertise and societal needs while fostering meaningful collaboration between diverse stakeholders.^{[1][2][3][4]}

Integrative multidisciplinary research has emerged as a critical paradigm for addressing these complex challenges through systematic approaches that combine diverse knowledge domains, methodologies, and perspectives. This research approach represents a fundamental shift from traditional disciplinary silos toward collaborative frameworks that recognize the interconnected nature of science, technology, and society. The development of integrative approaches reflects growing understanding that effective solutions to complex problems require not only technical expertise but also deep appreciation of

social contexts, policy implications, and community needs.^{[5][6][2][4][7][8][9]}

Science-Technology-Society Integration has evolved as a foundational framework for understanding the complex relationships between scientific knowledge, technological development, and societal impact. The Science-Technology-Society (STS) approach emphasizes the interdisciplinary nature of contemporary challenges, recognizing that scientific advancements have profound impacts on social, economic, and cultural aspects of life. This framework promotes critical thinking, civic engagement, and ethical considerations by positioning scientific and technological developments within broader social contexts.^{[6][2][10][4][5]}

Sociotechnical Systems Approaches provide sophisticated frameworks for understanding how technical and social elements interact within complex systems. Sociotechnical systems theory recognizes that successful technological implementation cannot be understood separately from the social context in which it occurs, emphasizing the need for integrated approaches that consider both technical functionality and social acceptance. These approaches have proven particularly valuable in areas such as information systems, organizational change, and technology adoption.^{[11][12][13][14][15][16]}

Transdisciplinary Research Methodologies represent advanced forms of integrative research that actively engage non-academic stakeholders as co-producers of knowledge. Transdisciplinary approaches go beyond traditional interdisciplinary collaboration to incorporate diverse perspectives from practitioners, policymakers, and communities throughout the research process. This methodology acknowledges that sustainable solutions to complex problems require not only academic expertise but also practical knowledge, local insights, and community engagement.^{[17][18][19][9]}

Knowledge Co-Production Frameworks have gained prominence as mechanisms for bridging the science-society gap through collaborative approaches that engage researchers and practitioners as equal partners in knowledge creation. These frameworks recognize that effective solutions to societal challenges require integration of scientific knowledge with practical experience, local knowledge, and community insights. Co-production approaches have demonstrated particular success in areas such as sustainability research, public health, and environmental management.^{[20][18][21][9][17]}

The urgency of addressing complex global challenges has intensified focus on research approaches that can deliver practical, scalable, and socially relevant solutions. This context creates both opportunity and pressure for integrative multidisciplinary research to demonstrate its capacity for generating transformative innovations that effectively bridge science, technology, and society.^{[3][22][23][1]}

Materials and Methods

This study employed a comprehensive systematic literature review methodology to examine integrative approaches in multidisciplinary research that bridge science, technology, and society. The research design incorporated analysis of theoretical frameworks, methodological papers, case studies, and empirical research spanning the period from 2003 to 2025.

Search Strategy: Multiple databases and sources were systematically searched including academic journals,

methodological publications, institutional repositories, and case study databases. Primary search terms included combinations of "integrative multidisciplinary research," "science-technology-society," "sociotechnical systems," "transdisciplinary research," "knowledge co-production," "integrative methodologies," and "science-society integration." Additional targeted searches examined specific frameworks, case studies, and applications.

Inclusion Criteria: Sources were selected based on: (1) focus on integrative approaches to multidisciplinary research; (2) examination of science-technology-society connections; (3) methodological contributions to integrative research; (4) empirical applications or case studies demonstrating integration; (5) theoretical frameworks for bridging disciplinary boundaries; (6) publication in credible academic venues or institutional sources; and (7) sufficient methodological detail for analysis.

Analytical Framework: The analysis was organized around six primary themes: (1) Science-Technology-Society Integration; (2) Sociotechnical Systems Approaches; (3) Integrative Research Methodologies; (4) Real-World Applications and Case Studies; (5) Challenges and Opportunities; and (6) Bridging Science and Society. Each theme was analyzed for theoretical foundations, methodological innovations, practical applications, and implementation challenges.

Case Study Selection: Particular attention was given to documented case studies that demonstrated successful implementation of integrative approaches across science, technology, and society domains. Cases were selected to represent diverse sectors, methodological approaches, and geographical contexts while providing sufficient detail for meaningful analysis of integrative processes and outcomes.

Framework Development: Based on comprehensive analysis, key integrative approaches were identified and systematically examined for their theoretical foundations, methodological characteristics, implementation requirements, and demonstrated effectiveness in bridging science, technology, and society.

Results

Science-Technology-Society Integration Frameworks

The analysis reveals sophisticated development of Science-Technology-Society (STS) integration frameworks that provide systematic approaches for connecting scientific knowledge, technological innovation, and societal needs.

STS Framework Development demonstrates evolution from simple awareness of science-society connections to sophisticated analytical frameworks that examine the complex interplay between scientific knowledge production, technological development, and social change. The integration of STS, Science-Technology-Society-Environment (STSE), and Socio-Scientific-Issues (SSI) under unified platforms delivers enriched, powerful, and organized pedagogy for advancing science education and research.^{[2][10][4][5][6]}

Educational Applications of STS frameworks have proven particularly effective in developing scientific and technological literacy while fostering critical thinking and civic engagement. Meta-analysis evidence indicates that STS approaches significantly improve students' scientific learning outcomes by connecting abstract scientific concepts with real-world applications and social contexts. The approach encourages students to analyze and evaluate scientific

information, question assumptions, and make informed decisions about science and technology issues.^{[24][25][6]}

Epistemological Foundations of STS integration rest on recognition that scientific knowledge and technological development are not neutral activities but are embedded within social, cultural, and political contexts. This perspective acknowledges that science and technology can only be understood in context, emphasizing the social construction of knowledge and the importance of examining underlying assumptions and power relations. Graduate STS programs demonstrate particular success in promoting cross-disciplinary integration and critical thinking by offering ways of integrating knowledge in areas impossible to grasp through single disciplines.^{[4][7][2]}

Policy and Civic Engagement represent critical dimensions of STS integration, with frameworks designed to equip students and researchers with knowledge and skills necessary for participating in discussions and decisions related to science and technology. STS education promotes civic engagement by addressing ethical implications of scientific and technological advancements while encouraging problem-solving skills through presentation of real-world challenges that require application of scientific knowledge and technological solutions.^{[5][6][4]}

Sociotechnical Systems Approaches

Theoretical Foundations of sociotechnical systems provide robust frameworks for understanding the complex interactions between social and technical elements within organizational and societal contexts. Sociotechnical theory conceptualizes systems in terms of social, technical, and environmental subsystems that interact to achieve specific objectives while balancing technical efficiency with social needs. The approach emphasizes joint optimization, seeking excellence in both technical performance and quality of people's work lives.^{[13][14][15][11]}

Design Methodologies for sociotechnical systems have evolved to provide systematic approaches for developing technologies and systems that effectively integrate human, social, and technical factors. Sociotechnical systems design methods consider human, social, and organizational factors as well as technical factors in system development. The approach recognizes that technological implementation and its effects cannot be understood separately from the organizational and social context of implementation.^{[12][15][16][11]}

Implementation Frameworks demonstrate sophisticated approaches for managing sociotechnical complexity in real-world contexts. The Building Information Modeling (BIM) implementation case study illustrates how sociotechnical approaches enable understanding of why technological adoption unfolds in unpredictable ways and requires constant-loop learning to maintain system alignment. The framework shows that successful implementation requires purposeful negotiation of intervention plans that support multiple end users' goals.^{[15][12][13]}

Innovation Assemblages represent advanced conceptualizations of how technical and social elements combine to generate innovation outcomes. Sociotechnical innovation in community-based tourism demonstrates how environmental change leads to implementation of new practices, platforms, and technologies while requiring integration of social, economic, and environmental considerations. Networks of innovation illustrate how

sociotechnical assemblages connect specialized knowledge and resources to inspire innovation through small-world arrangements.^{[16][23]}

Integrative Research Methodologies

Mixed Methods Integration has evolved sophisticated approaches for combining quantitative and qualitative research methods within unified frameworks that enhance explanatory power. The Integrative Mixed Methods (IMM) paradigm features parallelism in study design where integration begins with unified conceptualization of information as research evidence, enabling seamless data conversions between qualitative thematic categories and quantitative thematic variables. This approach allows recontextualization that relates statistically derived results back to their original qualitative context.^{[26][7]}

Transdisciplinary Approaches provide advanced methodologies for conducting research that actively engages non-academic stakeholders as co-producers of knowledge throughout the research process. Transdisciplinary case studies demonstrate systematic approaches for addressing societally relevant problems through collaborative research that involves practitioners, policymakers, and communities. The approach emphasizes mutual learning between science and society as the core of transdisciplinarity.^{[18][19][9][17]}

Case Study Methodologies have developed sophisticated frameworks for conducting integrative research through real-world problem examination. Transdisciplinary case studies provide practice-oriented knowledge for teaching fundamentals and principles of integrative research while strengthening competencies of researchers and raising awareness of challenges that arise during collaborative work. The Swiss Federal Institute of Technology has developed comprehensive frameworks for transdisciplinary case studies that include ontological, epistemological, methodological, and organizational considerations.^{[19][17][18]}

Epistemological Frameworks for integrative research provide theoretical foundations for understanding how different forms of knowledge can be systematically combined. Integrative research approaches include integral dialectical synthesis, unity-in-diversity, and analytico-synthetic integration strategies that enable reconciliation of apparent dichotomies between qualitative and quantitative methods. The Integrative Multidisciplinary (IMD) approach structures research projects in formalized phases that progress from disciplinary to interdisciplinary to transdisciplinary phases.^{[7][8][9]}

Real-World Applications and Case Studies

Social Innovation Examples demonstrate successful integration of science, technology, and society through community-focused solutions that address pressing social challenges. Clean water projects in developing nations exemplify integrative approaches that combine technical innovation with community engagement and social understanding. Mobile banking and financial services in India demonstrate how technological innovation can address social needs while considering cultural and economic contexts. Crowdfunding platforms illustrate how digital technologies enable global support for local social causes.^{[21][27][20]}

Technology Integration Applications showcase sophisticated approaches for implementing technological solutions that effectively address both technical requirements

and social needs. Integrated, multidisciplinary, and technology-enhanced learning approaches demonstrate how digital technologies can enhance educational outcomes while considering pedagogical and social factors. Sustainable energy solutions in Africa and Asia Pacific combine technical innovation with community engagement and environmental considerations.^{[25][12][20][21]}

Sustainability Applications illustrate comprehensive approaches that integrate environmental, social, and technological dimensions. Digital education programs utilize innovative technologies like virtual reality and augmented reality to provide learning opportunities while addressing social equity and accessibility concerns. Desert Control's liquid nano clay technology demonstrates integration of materials science, agriculture, and community development to address desertification challenges.^{[17][20][18][21]}

Community-Based Innovations exemplify successful integration of technical solutions with local knowledge and social contexts. Community-based tourism innovations demonstrate sociotechnical approaches that implement new environmental practices while considering economic, social, and cultural factors. Under The Mango Tree promotes beekeeping to increase agricultural productivity while providing market access, illustrating integration of technical knowledge with community development.^{[27][20][21][16]}

Challenges and Opportunities in Integration

Integration Challenges represent significant obstacles to successful implementation of integrative multidisciplinary research approaches. The complexity of coordinating diverse disciplines, methodologies, and stakeholders creates substantial management and coordination difficulties. Communication barriers arise from different disciplinary languages, conceptual frameworks, and methodological approaches. Resource availability including access to relevant materials, case studies, and technology may be limited in some contexts.^{[8][9][6][25]}

Methodological Difficulties emerge from the complexity of systematically combining different research approaches while maintaining scientific rigor. Integrative mixed methods research requires sophisticated approaches for converting qualitative data to quantitative variables and vice versa while preserving meaning and context. Quality control and validation become challenging when combining different types of evidence and analytical approaches. The development of appropriate evaluation criteria for integrative research remains an ongoing challenge.^{[9][26][7][8]}

Institutional Barriers continue to impede the full development and implementation of integrative research approaches. Traditional academic structures organized by disciplinary departments create barriers to promotion and recognition for integrative researchers. Funding mechanisms often favor single-discipline projects, limiting resources available for collaborative initiatives. Educational curricula and evaluation systems may not adequately support or recognize integrative approaches.^{[6][4][8]}

Future Directions indicate continued evolution toward more sophisticated integrative approaches that leverage technological advances and enhanced stakeholder engagement. The integration of artificial intelligence, big data, and digital platforms creates new opportunities for data integration and collaborative analysis. Growing recognition of the importance of science-society integration is driving institutional changes and new funding mechanisms. The

development of specialized journals and publication platforms for integrative research indicates growing academic acceptance.^{[22][1][3][9]}

Discussion

The analysis reveals that integrative approaches in multidisciplinary research have evolved into sophisticated frameworks capable of effectively bridging science, technology, and society through systematic methodological innovations and practical applications. The development of Science-Technology-Society integration, sociotechnical systems design, and transdisciplinary methodologies represents significant advances in research approaches that can address complex challenges requiring diverse expertise and stakeholder engagement.^{[1][13][22][7][18][5]}

Methodological Innovation Trajectories demonstrate clear evolution from simple awareness of interdisciplinary connections toward sophisticated frameworks for systematic integration of diverse knowledge domains. The development of Integrative Mixed Methods approaches illustrates how qualitative and quantitative research traditions can be systematically combined to generate enhanced explanatory power. Similarly, transdisciplinary case study methodologies demonstrate how academic research can be effectively integrated with practical knowledge and community insights.^{[2][26][7][18][19][9]}

Theoretical Foundation Development has provided robust conceptual frameworks for understanding how science, technology, and society interact in complex systems. Sociotechnical systems theory offers particularly valuable insights into how technical and social elements must be jointly optimized to achieve successful outcomes. The theoretical development of Science-Technology-Society frameworks provides essential understanding of how scientific knowledge and technological development are embedded within social contexts.^{[14][11][13][4][15][22][2]}

Practical Application Success demonstrates that integrative approaches can generate transformative outcomes when properly implemented. Case studies from construction industry BIM implementation, community-based tourism innovation, and social impact initiatives illustrate how integrative frameworks enable successful navigation of complex technical and social requirements. These applications demonstrate that integration is not merely theoretical but can be operationalized to achieve practical outcomes.^{[12][20][21][16][27]}

Scale and Context Considerations reveal that successful integration requires careful attention to scale, context, and stakeholder engagement. Transdisciplinary case studies demonstrate that effective integration cannot occur automatically but requires systematic planning and implementation across disciplinary, interdisciplinary, and transdisciplinary phases. Community-based innovations illustrate how local contexts and stakeholder needs must be carefully considered in designing integrative approaches.^{[18][8][16][9][27]}

Quality and Rigor Maintenance represents a critical challenge for integrative research that seeks to maintain scientific standards while incorporating diverse forms of knowledge. The development of quality control mechanisms for integrative mixed methods research demonstrates how scientific rigor can be maintained while enabling systematic integration of qualitative and quantitative approaches. However, questions remain about appropriate evaluation

criteria and peer review processes for truly integrative research.^{[26][7][8][9]}

Institutional Transformation Requirements highlight the need for continued evolution of academic structures, funding mechanisms, and evaluation criteria to support integrative research. The development of specialized journals and publication platforms indicates growing recognition of integrative research value. However, significant barriers remain in traditional academic career structures and promotion criteria that favor disciplinary specialization.^{[3][4][22][8][1]}

Technology Enablement Opportunities create new possibilities for integrative research through digital platforms, artificial intelligence, and enhanced communication technologies. Technology-enhanced learning approaches demonstrate how digital tools can facilitate integration across disciplines and stakeholders. Innovation networks illustrate how technological platforms can enable new forms of collaboration and knowledge sharing. However, technology alone cannot address fundamental challenges related to disciplinary differences and institutional structures.^{[23][25][22][9]}

Global and Local Balance emerges as a critical consideration for integrative research that seeks to address both universal principles and local contexts. Social innovation examples demonstrate how global technologies and approaches must be adapted to local social, cultural, and economic contexts. Community-based innovations illustrate the importance of engaging local knowledge and stakeholder perspectives in developing integrative solutions.^{[20][21][16][27]}

Conclusion

This comprehensive analysis demonstrates that integrative approaches in multidisciplinary research have evolved into sophisticated frameworks capable of effectively bridging science, technology, and society through systematic methodological innovations and practical applications. The development of Science-Technology-Society integration, sociotechnical systems design, transdisciplinary case studies, and knowledge co-production methodologies represents significant advances in research approaches that can address complex contemporary challenges requiring diverse expertise and meaningful stakeholder engagement.

The evidence reveals that successful integration occurs through systematic frameworks that recognize the interconnected nature of scientific knowledge, technological innovation, and social contexts. Science-Technology-Society approaches provide essential foundations for understanding how technical developments are embedded within broader social systems, while sociotechnical frameworks offer practical methodologies for designing and implementing technologies that balance technical efficiency with social needs and acceptance.

Transdisciplinary methodologies and knowledge co-production approaches demonstrate particular promise for generating transformative outcomes by actively engaging non-academic stakeholders as partners in research processes. These approaches acknowledge that sustainable solutions to complex problems require not only technical expertise but also practical knowledge, local insights, and community engagement throughout the research lifecycle.

Real-world applications across social innovation, sustainable technology, and community-based solutions illustrate the practical potential of integrative approaches for addressing

pressing societal challenges. However, significant obstacles remain including methodological complexity, institutional barriers, and coordination difficulties that require continued attention and strategic intervention.

The success of integrative multidisciplinary research depends on continued development of methodological frameworks that maintain scientific rigor while enabling systematic combination of diverse knowledge domains. Institutional transformation is essential to provide appropriate support structures, evaluation criteria, and career pathways that recognize and reward integrative research contributions.

Future progress will require sustained investment in methodological innovation, institutional reform, and capacity building to create enabling conditions for integrative research that can effectively bridge science, technology, and society. The increasing complexity of global challenges makes such integrative approaches not merely beneficial but essential for generating the transformative solutions needed to address humanity's most pressing problems.

The evidence compellingly demonstrates that integrative multidisciplinary research provides essential frameworks for connecting scientific knowledge with technological innovation and societal impact. Realizing this potential requires continued commitment to developing sophisticated methodological approaches, supportive institutional structures, and collaborative cultures that can generate meaningful integration across the boundaries of science, technology, and society.

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