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# Causality and Explanation in Modern Scientific Theories

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**ABSTRACT:** Causality and explanation are fundamental pillars of modern scientific theories, crucial for understanding the interconnectedness of phenomena and constructing knowledge in scientific discourse. Causality refers to the relationship between cause and effect, forming the basis of scientific inquiry and shaping how theories are formulated and explanations structured. In contemporary discourse, causality extends beyond simple linear relationships to encompass intricate interactions and feedback loops across disciplines like physics, biology, sociology, and beyond. Rigorous methodologies and theoretical frameworks are essential for capturing these complexities in natural and social phenomena. Moreover, modern scientific explanations transcend mere description by aiming to uncover underlying mechanisms and principles governing observed phenomena. Theories across disciplines from quantum mechanics to neuroscience strive to provide frameworks that elucidate not just what happens, but why and how it happens.

**KEYWORDS:** Causality, scientific explanation, interdisciplinary, complexity, methodology.

## I. INTRODUCTION

Causality and explanation are foundational concepts in modern scientific theories, serving as cornerstones for understanding how phenomena are interconnected and how knowledge is constructed in scientific discourse. Causality, in its simplest form, pertains to the relationship between cause and effect, where events are understood to be the result of preceding causes. This concept not only underpins scientific inquiry but also influences how theories are formulated and explanations are structured. In contemporary scientific discourse, the notion of causality has evolved beyond linear relationships to encompass complex interactions and feedback loops across diverse disciplines such as physics, biology, sociology, and beyond. Understanding causality in this broader context requires rigorous methodologies and theoretical frameworks that can capture the intricacies of natural and social phenomena. Moreover, explanations in modern scientific theories go beyond mere description; they aim to uncover the underlying mechanisms and principles that govern observed phenomena. From quantum mechanics to neuroscience, theories strive to provide explanatory frameworks that elucidate not just what happens, but why and how it happens [1].

## II. REVIEW OF LITERATURES

**Hedström, et al (2010)** This article critically reviews mechanism-based explanations in the social sciences and philosophy of science. It examines the philosophical perspective on causation and the covering-law account, and then explores the application of mechanisms in social sciences. The final section discusses analytical sociology, including middle-range theory and agent-based simulations. Overall, it offers a comprehensive review of how mechanisms function within sociological explanations, providing insights into their theoretical underpinnings and practical applications.

**Thompson, R. P. (2010)** Thompson critiques evidence-based medicine (EBM), arguing that its reliance on randomized controlled trials (RCTs) over theoretical models undermines the validity of its causal claims. He highlights the criticisms of RCTs and suggests that EBM's hierarchical devaluation of theoretical models weakens its scientific robustness. This paper challenges the perceived 'gold standard' status of EBM by emphasizing the importance of theoretical frameworks in making valid causal inferences.

**Van Camp, W. (2011)** discusses principal theories and constructive theories in the context of quantum mechanics, referencing Einstein's distinction in special relativity. The paper argues for the importance of explanatory preferences and clarifies the conceptual strengths of principle theories. By focusing on principle theory approaches, Van Camp aims to provide a philosophical justification for their use in interpreting quantum mechanics, highlighting their explanatory power.

**Beer, et al (2012)** This paper addresses the problem of analysing counterexample traces in model checking. Using Halpern and Pearl's notion of causality, the authors define causes for specification failures and present them visually as red dots. They develop a polynomial-time algorithm to approximate these causes and implement it in IBM's Rule Base

PE. Their approach is tool-independent, offering a practical solution for identifying failures in complex traces, enhancing the user's understanding of counterexamples.

**Lange, M. (2013)** explores distinctively mathematical explanations in science, which provide a type of understanding that causal explanations cannot. These explanations are non-causal but show the explanandum to be more necessary than ordinary causal laws. By identifying the modal strength of facts in these explanations, Lange argues that distinctively mathematical explanations offer a unique and crucial form of scientific understanding.

**Leuridan, B. (2014)** proposes a causal-structural account of scientific theories, represented as sets of interrelated causal and credal nets. This contrasts with other accounts by emphasizing causality. Using classical genetics as a case study, the article demonstrates how this framework provides explanatory unification and insight into scientific explanations, highlighting the substantial role of causality in scientific theory representation.

**McCain, K. (2015)** examines the nature of explanation in science, its relation to understanding, and its role in generating scientific knowledge. By analysing inference to the best explanation, McCain highlights the unifying features of scientific explanation and supports the consensus view of the nature of science. This article underscores the importance of understanding explanation in science education and its implications for scientific knowledge.

**Felline, L. (2016)** Feline explores axiomatic reconstructions of quantum theory (ARQITs) and their explanatory power regarding quantum phenomena, particularly quantum nonlocality. Through case studies, the paper argues that ARQITs can provide genuine explanations but acknowledges their limitations in excluding mechanical quantum theories. The article reevaluates the epistemic status of ARQITs, emphasizing their role in explaining quantum phenomena.

**Matic, A. E. (2017)** Matic discusses the complexities and risks of causal explanations, particularly in science and philosophy. The paper analyses how our desire to explain phenomena using known notions can lead to errors and misjudgements. It also examines the impact of modern physics on the concept of causality and its implications for legal regulation and law enforcement, advocating for careful consideration of causal inferences to avoid errors.

### III. HISTORICAL EVOLUTION OF CAUSALITY

The concept of causality has evolved significantly over centuries, from its philosophical roots in ancient Greece to its formalization in early modern science by figures like Newton and Descartes. This historical trajectory highlights how different epochs and scientific revolutions have shaped our understanding of causality, from mechanistic determinism to probabilistic causation in the quantum era [2].

### IV. PHILOSOPHICAL FOUNDATIONS OF CAUSALITY

Philosophically, causality has been debated extensively, from Hume's critique of necessary connection to Kant's transcendental idealism. Contemporary philosophy of science continues to grapple with questions about the nature of causation: Is causality fundamental or emergent? How do causal relationships interact with laws of nature and probabilistic outcomes?

### V. ROLE OF CAUSALITY IN SCIENTIFIC EXPLANATION

Causality plays a central role in scientific explanation by providing a framework to connect phenomena with underlying mechanisms or laws. Scientific theories often aim not only to describe but also to explain natural phenomena by identifying causal relationships that underpin observed regularities. The explanatory power of a theory often correlates with its ability to elucidate causal mechanisms [3].

### VI. TYPES OF SCIENTIFIC EXPLANATIONS

Scientific explanations vary across disciplines and paradigms. They can range from deductive-nomological explanations rooted in laws of nature to statistical and probabilistic explanations prevalent in complex systems and quantum mechanics. Understanding the diversity of explanatory strategies helps appreciate the role of causality in different scientific contexts [4].

### VII. CHALLENGES AND LIMITATIONS IN CAUSAL REASONING

Despite its utility, causal reasoning faces challenges, such as distinguishing between correlation and causation, dealing with complex systems where multiple causes interact, and addressing the role of context and background conditions. These challenges underscore the ongoing refinement and critique of causal methodologies in contemporary science [5-6].



## VIII. EMERGING TRENDS AND FUTURE DIRECTIONS

Contemporary scientific research is witnessing novel approaches to causality and explanation, influenced by advances in computational modelling, artificial intelligence, and complex systems theory. These interdisciplinary trends promise to deepen our understanding of causality in fields ranging from neuroscience and ecology to economics and social sciences [7-9].

## IX. CONCLUSION

Causality remains a cornerstone of scientific inquiry, evolving with the advancement of methodologies and theoretical frameworks. Its historical evolution from ancient philosophical roots through early modern formalization to contemporary complexity underscores its foundational role in scientific explanations. Philosophically, debates surrounding causality—from Humean scepticism to Kantian transcendentalism continue to inform contemporary discussions, highlighting its nuanced role in scientific reasoning.

In scientific practice, causality plays a pivotal role by connecting observable phenomena with underlying mechanisms or laws, enriching our understanding through explanatory frameworks. The diversity of scientific explanations from deductive-nomological to probabilistic reflects varying disciplinary approaches and paradigms, each leveraging causality differently. However, challenges persist, such as distinguishing correlation from causation in complex systems and addressing contextual influences on causal relationships. These challenges necessitate ongoing refinement and critique of causal methodologies in contemporary scientific research. The emerging interdisciplinary trends in computational modelling, artificial intelligence, and complex systems theory promise new insights into causality across diverse fields. These advancements are poised to deepen our understanding of complex causal relationships in neuroscience, ecology, economics, and the social sciences, paving the way for novel approaches to scientific explanation and discovery.

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