INTERNATIONAL JOURNAL
FOR INNOVATION
EDUCATION AND RESEARCH
ISSN: 2411-2933

Journal URL: https://scholarsjournal.net/index.php/ijier

DOI: https://doi.org/10.31686/ijier.vol14.iss1.4293

Scientific Revolutions as Categorical Transformations: Rationality, Structural Invariance, and the Evolution of Knowledge

Alexander Wang

Guangzhou Vocational University of Science and Technology

Abstract

Philosophical accounts of scientific theory change face a persistent dilemma: how can episodes of radical conceptual transformation remain rationally constrained? Kuhnian paradigms emphasize rupture but lack formal criteria for tracking structural continuity, while structural realism preserves continuity at the cost of leaving transformation itself unexplained. Existing approaches offer theories of comparison, but not theories of transformation. This paper develops a categorical reconstruction of scientific theory change that resolves this impasse. Scientific theories are modeled as structured objects and inter-theoretic transitions as morphisms governed by compositional and invariance constraints. Revolutionary change is thereby reconceived as structured reconfiguration rather than epistemic breakdown. This framework provides precise criteria for theory identity, structural continuity, and rational comparability across conceptual change. By shifting explanatory priority from semantic content to morphic structure, the categorical perspective reconceives scientific rationality as coherence under transformation. Scientific knowledge emerges not as static representation but as structured evolution governed by morphic constraints.

Key words: scientific Revolutions, category theory, structural Invariance, evolution of knowledge

1. Introduction: The Unresolved Problem of Rational Transformation

Scientific theories undergo transformation. These transformations are not merely additive extensions but involve deep restructuring of conceptual frameworks. Yet scientific revolutions are not regarded as irrational events. The replacement of Newtonian gravitation by general relativity did not constitute epistemic collapse but epistemic advancement.

This generates a central unresolved philosophical problem: **How can scientific theories undergo radical conceptual transformation while remaining rationally constrained?**

Existing philosophical accounts fail to resolve this tension.

Kuhn's theory of paradigms correctly emphasizes the discontinuity of scientific revolutions but undermines rational comparability by denying stable criteria for inter-paradigm evaluation (Kuhn 1962). Structural realism preserves rational continuity by emphasizing invariant structure but offers no formal account of structural transformation itself (Worrall 1989; Ladyman 1998). The semantic view provides formal representation but treats theories as static model classes rather than dynamically evolving structures (Suppes 1960; van Fraassen 1980).

These approaches share a common limitation: they provide theories of representation or comparison, but not theories of transformation.

Without a formal account of transformation, the rationality of scientific change remains philosophically unexplained.

This paper argues that scientific theory change is best understood as categorical transformation. Category theory provides a formal framework for representing structured systems and their transformations. Scientific theories can be modeled as structured objects, and theory transitions as morphisms governed by compositional constraints.

Drawing on historical case studies of Galileo's theory of motion and Einstein's theory of relativity, this paper shows that scientific revolutions can be understood as category-theoretic transformations that preserve logical coherence while reconfiguring theoretical relations. By presenting scientific creativity as a systematic process of reconceptualization, I argue that category theory provides a formal mechanism for conceptual change, offering a new perspective on the philosophy of science.

1.1 Theoretical gap

Previous accounts fail in three ways:

1. Logical empiricists neglect the generative mechanisms of innovation.
2. Historical accounts lack formal precision regarding conceptual structure.
3. Cognitive accounts cannot explain rational structural coherence.

This leaves a conceptual gap that category theory is uniquely suited to fill.

1.2 Why category theory

Category theory's core constructs—objects, morphisms, functors, natural transformations—provide a powerful vocabulary for expressing:

A. conceptual structures,
B. inferential relations,
C. theory translations,
D. and structural transformations.

As Spivak (2014) demonstrates, categorical tools can model complex conceptual systems beyond mathematics. Baez & Stay (2011) further illustrate its applicability to reasoning and physics, supporting its use in epistemology.

1.3 Contributions

This paper offers three claims:

1. Scientific creativity can be modeled formally as natural transformations between theoretical functors.
2. Scientific theories can be represented as categories encoding conceptual relations.
3. Major historical breakthroughs (Galileo, Einstein) instantiate categorical structure-preserving transformations.

1.4 Structure

Section 2 reviews philosophical and mathematical background.

Section 3 introduces the categorical model.

Section 4 presents case studies.

Section 5 concludes.

2. Philosophical and Mathematical Background

2.1 Philosophical accounts of creativity

Hanson (1958) emphasized the interpretive nature of scientific observation. Kuhn's paradigms (1962) and Lakatos's research programmes (1970) focused on conceptual frameworks. While these analyses capture the qualitative nature of conceptual change, they do not provide a formal account of structural transformation.

Structuralist philosophy (Balzer et al. 1987; van Fraassen 1989) views theories as families of structures. Yet this tradition has lacked a single mathematical formalism capable of handling structure-preserving conceptual change.

Category theory fills this gap.

2.2 History and Definition of Category Theory

Aristotle's *Categories* explored the classification of objects recognizable to humans. In modern mathematics, however, categories possess a precise definition. A category is, at its core, a collection of objects linked by morphisms that preserve structure. Category theory, introduced by MacLane and Eilenberg in 1945, has since permeated nearly every branch of mathematics, serving as a universal language for abstract structures.

Definition 1: A category C includes:

(1) A collection of a set of objects O; as a mathematical object, it has internal operation rules;

(2) A collection of morphisms, in which morphisms (or arrows, functors f) $f: X \to Y$; X is the domain of f, and Y is the codomain, denoted as $\mathrm{dom}(f) = X, \mathrm{cod}(f) = Y$. $\mathrm{Hom}(X, Y)$ to denote the entirety of arrows from object X to Y. This is a collection, as shown in Figure 1(a) below.

For any object X, there is an arrow, as shown in Figure 1(b) below, $1X: X \to X$, 1X is named the identity of X, which is the unit law. For any f, $f \circ 1X = f = 1Y \circ f$. There are two arrows f and g, such that $\mathrm{cod}(f) = \mathrm{dom}(g)$, as shown in Figure 1(c) below. $g \circ f$, denote the composition of f and g. A graph is said to be "commutative" when any arrow composite has the same range and equal domains. As shown in Figure 1(d) below.

$$X \xrightarrow{f} Y \qquad X \xrightarrow{1X} X \qquad Z \xleftarrow{g} Y \xleftarrow{f} X$$

$$Z \xrightarrow{g \circ f} X$$

（a） （b） （c）

With functors as morphisms, all categories form a larger Cat. So naturally, we have the notion of isomorphism between categories: as isomorphisms within other categories, two categories X, Y are isomorphic if and only if there are two functors F: C→D, G:D→C, so that both sides are identity functors after they are combined, as shown in Figure 2 below:

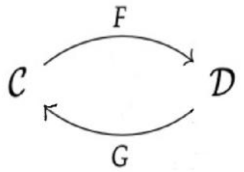

Figure2 Category

(3) $G \circ F = idC,\ F \circ G = idD$

The concept of "isomorphism" is defined by a compositional functor, a thinking way that is consistent with the philosophy of category theory, which defines mathematical structures in terms of morphisms. In other words, the basic ideas of category theory reflect the way we organize the structure of information. The idea that morphism represent category has been widely used in the foundations of mathematics. For example, a subgroup can be equivalently regarded as a single group homomorphism, and the quotient group (or normal subgroup) of a group can be equivalently regarded as a full group homomorphism; thus, a subset can be equivalently defined in terms of injective, a quotient can be equivalently expressed in terms of surjective. Developing this idea, the concept of homology which measuring the difference between the exact sequence and the surjective of the category can be defined.

From the above definition, the basic idea of category theory is to study the properties of an object through the relationship between objects. This relationship is usually defined by morphism, so that morphism reflects the structure of mathematical objects. "Structure" refers to a class of mathematical objects described by axioms, and mathematics is concerned with "structure" rather than a specific "object". Bourbaki believe that the structure in mathematics is divided into three categories: algebraic structure (group, ring, field), order structure (partial order, total order) and topological structure (limit, continuity, connectivity, neighborhood). With the improvement of the abstraction degree and the expansion of the field of mathematics, the structure itself is the "category theory" as a study object.

Category theory is the study of mathematical structures in a concise, general and abstract way. For example, in topology, a doughnut is the same as a coffee cup. According to category theory, they are isomorphic in a category Top, the object is a topological space, and the arrow is a continuous map (i.e., continuous transformation), so a doughnut and a coffee cup are homeomorphic.

The advantages of category theory are as follows:

A very obvious trend in the development of modern science is the division between disciplines; knowledge in different fields seems to be divided more and more finely, and it is more and more difficult for us to have an overall understanding of it. At the conceptual level, category theory unifies definitions and concepts from different branches of mathematics. Category theory has partially unified the division of mathematics at the conceptual level, and it has found the same conceptual basis among different branches of mathematics.

It's promising to study difficult interdisciplinary scientific problems applying the structural ideas of category theory. For example, physicists apply category theory to solve the problem of topological condensed matter. A good study of problems in mathematical logic. Applying the structured thinking mode of category theory, the structured thinking mode of the brain is researched, and through the Bi-interpretation perspective of the category theory, the structural characteristics of the brain's thinking is interpreted.

3. Categorical Framework for Scientific Revolution

3.1 Transcendence of creative thinking

As early as in ancient Greece, the study of human rational thinking has already begun and established. Plato vividly expresses his philosophical "idea" view through the cave metaphor, in which the "idea" is seen as a being that illuminates everything. And to reach knowledge of this idea, mind must go through a series of turns, from shadows to things, to firelight, to things outside the cave, and finally to the sun. The path of individual liberation from opinions and phenomena is the same path .

Parmenides was the first to put forward the schema of "thought" (rational thinking) which is opposite to feeling. This is the first real thinking model in the study of human reason. Later philosophers including Kant modified and developed this model.

As shown in Figure 3, Parmenides classified objective matter and subjective spirit, and proposed two philosophical categories of "existence" and "non-existence", "feeling" and "thought". In it, what can be "thought is the same as that which can be", and feeling and non-being are the same. Parmenides gave a negative answer to the question of whether there is a connection between existence and non-existence, feeling and thought. Rational cognition leads to the "path of truth", while perceptual cognition leads to It is the "opinion road", the two roads are diametrically opposed.

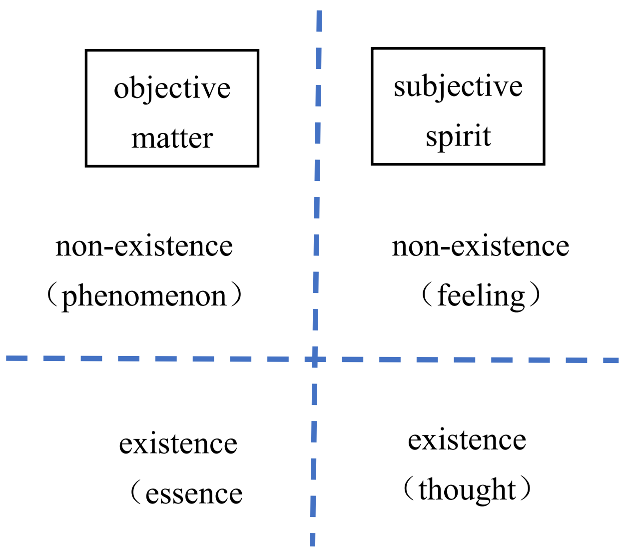

Figure 3 Parmenides' model of rational thinking

After the Renaissance, modern philosophy, physics, mathematics, and neuroscience have developed by leaps. The cognition of rational thinking has undergone a huge change, and Descartes put forward the famous slogan "cogito, ergo sum (I think, therefore I am)", which is logically impossible to refute, that is, all the world of experience, all senses and all idea are some kinds of illusion. But the existence of this activity itself indicates a being, which is "I", and rational cognition of the world can only proceed from doubt. From the perspective of human philosophy, Cassirer, modern philosopher and scientist, regards man as a symbolic animal, and only in man, the question of possibility and reality can be realized. Only in man, mythical, religious, linguistic, artistic, historical and scientific symbols can be created and applied. Man use symbols to create culture, and the creation and using of symbols is the difference between humans and animal.

In the 20th century, with the establishment of the two major scientific theories of relativity and quantum mechanics, people have a deeper understanding of the characteristics and structure of scientific theories. Now generally, it is believed that the structure of a scientific theory consists of three elements: concepts; basic principles, linking to these concepts; the logical conclusions, i.e., various specific special laws and predictions derived from these concepts and principles. Among them, basic concepts, basic principles and propositions constitute the core elements of theory.

Einstein said, "in the structure of my thinking, written or spoken words do not seem to have any role... The various concepts that appear in our thinking and our verbal expressions are logically free creations of the mind, they cannot be derived inductively from sensory experience. The reason this is not so easy to notice is only because we are so accustomed to associating certain concepts and their relations (propositions) with certain sensory experiences in such certainty that we are unaware that such a logical an insurmountable chasm that separates the world of sensory experience from the world of concepts and propositions".

According to Einstein, "There is nothing that can be said a priori about the formation of concepts and how they are related to one another, and how we oppose these concepts to sensory experience. Comparing these with the rules of the game, in the game, the rules themselves are arbitrary, but the game is possible only if they are strictly followed. But such rules are never final, and they will only be effective if they are obeyed in a specific field".

Reviewing the historical development of rational thinking, it’s obviously that the transcendence of brain thinking, beyond the world of experience, and even beyond human intuition, which guided scientists to establish various scientific theories.

3.2 Category Theory and Natural Transformations

In order to study the structural characteristics of brain thinking, it is necessary to further study the structural characteristics of scientific theories, that is, to categorize and axiomize scientific theories. In this way, from the perspective of categorization, the isomorphic characteristics of theoretical models of different disciplines and the categorization characteristics of brain thinking can be shown.

Definition 2:

A scientific theory category C includes:

(1) A collection T of a set of objects; the set contains an operator O and its operation rules;

(2) A collection of morphisms, in which morphisms (or arrows, functors f) $f: T \to T$; f is said to be an automorphic functor induced by object collection. Let $\mathrm{Hom}(T,T)$ denote the entirety of arrows from object T to T.

Definition 3:

A scientific theory is a $\mathrm{Hom}(T,T)$.

The conception of scientific theory is defined through the predicate "is a $\mathrm{Hom}(T,T)$". As far as scientific theory is concerned, the predicate $\mathrm{Hom}(T,T)$ represents a mathematical structure, which is the basic structure of scientific theory. If only the mathematical structure of this theory is considered, this basic structure is sufficient to explain the characteristics of the theory itself.

3.3 The Category Theory Model of Structured Thinking

Definition 4:

$F, G: A \to B$ is a functor, a natural transformation, or a morphism $t: F \to G$, is collection of $t_x: x \in \mathrm{Ob}(A)$ such that:

(1) $t_x: F(x) \to G(x)$ is a morphism in category B, and

(2) For each morphism in A (internal operation in A) $\phi: x \to y$, follow the commutative diagram is shown in Figure 4:

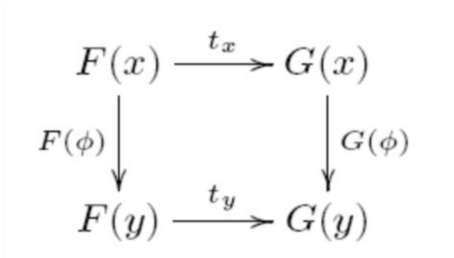

Figure 4 natural transformation

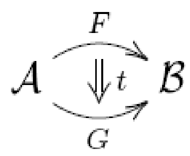

Figure 5 simplified commutative diagram

Sometimes, commutative diagram is simplified as shown in Figure 5, indicating that $t: F \to G$ morphism.

The morphism between functors is named the natural transformation of the functor. There is a mathematical structure of natural transformations between functors, that is, a set of objects, morphisms, and morphisms between morphisms, which is called a 2-category. A general category is called a first-order category. For any category K of order 2, there is also a natural equivalent notion that is weaker than isomorphism. For two objects X, Y in any K, the two objects are equivalent in K, if the composite map of two morphisms $f: X \to Y$, $g: Y \to X$ and the identical map meet the demand of definition of higher-order isomorphism.

4. Case Studies

4.1 Galileo

By investigating the process of scientific theory discovery, the category theory model of structured thinking of scientific theory is to be established. The father of modern science, Galileo, faced a lot of challenging problems when he created new physics, such as the following:

1. How to find simple laws from the complex appearances, and what principles and tools can be based on? 2. Compared with the old theories, how can the proposed laws make breakthroughs in the interpretation of experience? 3. What kind of mathematical properties (structural) should the found laws have?

The first question, Galileo, combined with his own study of motion, believed that the natural world itself is simple and harmonious. The language of mathematics is simple and clear, and scientific research should follow this language to explore the secrets of nature. This grand book (universe) is written in the mathematical language, and its characters are triangles, circles or other geometric figures, without which it is impossible to humanly understand a word; without these one is wandering in a dark labyrinth.

The second question, Aristotle's theory is closely integrated with people's daily experience. Compared with Galileo's new theory, we even can say that Aristotle's theory has more support from empirical evidence of various motions on the earth's surface. Galileo's argument revealed that existing experience must be reinterpreted critically, thus allowing his theory to be reborn from the new interpretation. Galileo's interpretation also takes man out of the Aristotle's cave of sensory experience.

The third question is very crucial, even determining whether the new theory can become a scientific theory. To answer this question, Galileo proposed the principle of inertia (relativity) principle and Galileo transformation. The principle of inertia became the foundation of physics, and this principle evolved into the basic idea of modern physics: Symmetry determines the equations of physics.

The $Ox'y'z'$ coordinate system moves at a constant speed u relative to the $Oxyz$ system. When $t=t'=0$, O coincides with O'. The space-time correspondence between the two systems is

$$\begin{cases} t = t' \\ r = r' + ut' \\ v = v' + u \end{cases} \qquad (1)$$

This is the Galileo transformation. The transformation is written in matrix T, T connects the two systems and keeps the corresponding physical phenomena consistent in the two systems, which is the isomorphism of the two systems, see Definition 4 and Figure 4.

Similarly, if we propose a different transformation relation (non-isomorphism functors), then a different scientific theory is proposed. For example, the transformation is Lorentz transformation, then the special relativity theory is proposed. These theories are isomorphic (physically equivalent theories), if the proposed functors have natural transformation which have properties of composite mappings and identity mappings. In Fig. 5, the A coordinate system and the B coordinate system are isomorphic if the transformation is Lorentz transformation, and they are physically equivalent special relativity.

4.2 Einstein: General Relativity as a Paradigm of Creative Reasoning

Another paradigmatic instance often regarded as the pinnacle of human creative reasoning is the formulation of general relativity. Within the framework of special relativity, all inertial reference frames moving with constant velocity are physically equivalent, and the laws of physics are required to assume the same form in any such frame. Seeking to extend the principle of relativity, Einstein posed a profound question: Should the laws of physics also remain invariant in accelerated reference frames? In parallel, he engaged deeply with the problem of how to incorporate the phenomenon of gravitation into the relativistic theoretical structure.

Einstein's reasoning was crystallized in a celebrated thought experiment: an observer enclosed within an elevator is unable to determine whether the forces they experience arise from uniform acceleration or from the gravitational pull of the Earth. The impossibility of such a distinction stems from the fact that no physical experiment can discriminate between an inertial field and a gravitational field. Unlike other fundamental forces, gravity cannot be locally compensated by a quantity such as acceleration. Einstein therefore advanced the radical proposal that gravity should be reinterpreted not as an external force but as an intrinsic manifestation of spacetime curvature.

From this perspective, the equivalence principle asserts that gravitational effects can always be locally canceled by an appropriate choice of accelerated reference frame. Consequently, non-inertial systems possessing such equivalence may be transformed into inertial systems, provided that the additional influence of a gravitational field is duly incorporated. This conceptual leap—recasting gravitation as a property of spacetime itself—constitutes the creative and transcendent reasoning that ultimately gave rise to general relativit.

Moreover, this mode of reasoning exhibits a striking structural duality with the notion of equivalence in 2-category theory. When formalized within the language of category theory, one may regard functors F and G as mapping Einstein's thought-experimental scenarios into distinct theoretical frameworks: F corresponds to Newtonian mechanics, whereas G corresponds to general relativity. The natural transformation t encodes the equivalence principle. Importantly, t does not directly connect the empirical scenarios; rather, it establishes a bridge at the theoretical level, systematically transforming one representation (F) into another (G). By employing the categorical notion of natural transformation (cf. Figure 4), Einstein's reasoning process can thus be structurally recast as a functorial diagram (Figure 6), highlighting the deep correspondence between scientific creativity and categorical abstraction.

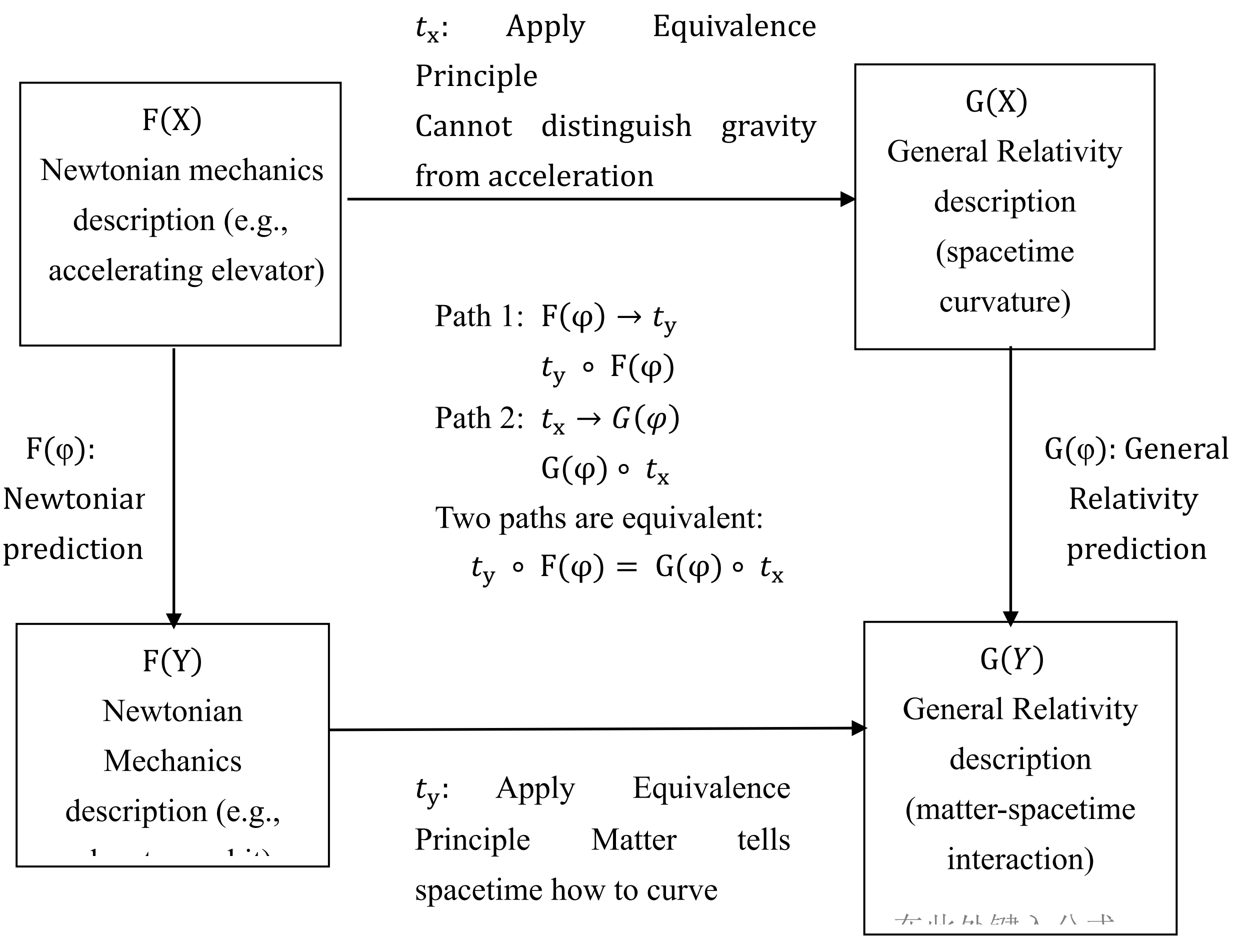

Figure 6. The reasoning process of general relativity and its structural

Constitution of the Diagram

Two objects (upper row):

F(X): The Newtonian description of situation X (e.g., an accelerating elevator).

G(X): The general relativistic description of the same situation X.

Two objects (lower row):

F(Y): The Newtonian description of situation Y (e.g., a planet orbiting the sun).

G(Y): The general relativistic description of the same situation Y.

Two functors (vertical arrows):

F(φ): F(X) → F(Y)represents the Newtonian prediction, i.e., the derivation of the physical relation from situation X to situation Y within the Newtonian framework.

G(φ): G(X) → G(Y) represents the general relativistic prediction, i.e., the corresponding derivation within the framework of general relativity.

Natural transformations (horizontal arrows, i.e., the application of the equivalence principle):

t_x: F(X) → G(X) transforms the Newtonian description of the accelerating elevator into the general relativistic description of curved spacetime, by applying the equivalence principle ("a local inertial frame cannot distinguish between gravity and acceleration").

t_y: $\mathrm{F(Y)} \rightarrow \mathrm{G(Y)}$transforms the Newtonian description of planetary orbits into the relativistic description ("matter tells spacetime how to curve, and spacetime tells matter how to move"). In this functorial transformation t_y, the known relation from special relativity between the energy-momentum tensor （$\boldsymbol{T_{\mu\nu}}$） and spacetime curvature is explicitly invoked.

This diagram demonstrates that Einstein's creative leap was not a discontinuous jump but rather a structured and inferential process of natural transformation. The equivalence principle (t) functions as a kind of "theoretical translator", systematically and consistently converting the Newtonian framework (F) into the general relativistic framework (G), ultimately yielding the relation:

$$G_{\mu\nu} = \frac{8\pi\mathrm{G}}{\mathrm{C}^4} T_{\mu\nu}$$

The commutative diagram thus captures the essence of Einstein's creative reasoning: structured thinking articulated through categorical transformation. Category theory proves to be a powerful tool for characterizing the structural logic of creative reasoning.

Moreover, the notions of category theory—functors and natural transformations—suggest that the human mind exhibits transcendent creative capacities, which manifest prominently in the process of major scientific discoveries. Each scientific theory is embodied in its own mathematical structure, and such structures arise from the free creativity of scientists. In exercising this creativity, scientists—whether consciously or unconsciously—employ categorical reasoning. The abstract and structural viewpoint of category theory simplifies complex and profound thought processes, rendering them clear and systematic. Hence, category theory is indispensable for the expression and reasoning of knowledge. Thinking in categorical terms is increasingly emerging as a paradigmatic model for innovative scientific theorizing.

Both cases demonstrate creativity as structural reorganization rather than isolated insight, confirming the adequacy of categorical representation.

5. Conclusion

In this paper, I have shown that revolution in science is not a random process but a systematic transformation between conceptual frameworks. Using **category theory** as a formal tool, I have modeled scientific innovation as **functorial transformations** that preserve structural coherence while altering the relationships between core concepts. By applying this model to historical case studies, I demonstrated that **Galileo's reformulation of motion** and **Einstein's theory of relativity** are best understood as examples of **category-theoretic shifts**, where logical structure is preserved while new conceptual relations emerge.

This work contributes to the philosophy of science by offering a **formal account of scientific creativity**. It integrates **mathematical theory** with **epistemological insights**, challenging traditional models of creativity that treat it as merely intuitive. By formalizing creativity as **structural reorganization**, I provide a new lens through which we can understand scientific progress—not as a series of isolated leaps, but as a **rational process of conceptual reorganization**. Further research may explore higher-order transformations and the role of **topos theory** in scientific reasoning, extending this framework to more complex systems and theories.

Bibliography

1. Kuhn, T. S. (1962). The Structure of Scientific Revolutions.
2. Baez, J., & Stay, M. (2011). *Physics, topology, logic and computation: A Rosetta Stone*. In B. Coecke (Ed.), *New Structures for Physics* (pp. 95–172). Springer.
3. Balzer, W., Moulines, C. U., & Sneed, J. D. (1987). *An Architectonic for Science: The Structuralist Program*. Springer.
4. Butterfield, J., & Isham, C. (1998). A topos perspective on the Kochen–Specker theorem. *International Journal of Theoretical Physics*, 37(11), 2669–2733.
5. Cheng, E. (2015). *How to Bake π: An Edible Exploration of the Mathematics of Mathematics*. Basic Books.
6. Eilenberg, S., & Mac Lane, S. (1945). *General theory of natural equivalences*. *Transactions of the American Mathematical Society*, 58(2), 231–294.
7. Feferman, S. (1999). *Logic, logics, and logicism*. *Notre Dame Journal of Formal Logic*, 40(1), 31–54.
8. Galileo, G. (1638/1954). *Dialogues Concerning Two New Sciences* (H. Crew & A. de Salvio, Trans.). Dover Publications.
9. Hanson, N. R. (1958). *Patterns of Discovery: An Inquiry Into the Conceptual Foundations of Science*. Cambridge University Press.
10. Hempel, C. G. (1965). *Aspects of Scientific Explanation*. Free Press.
11. Kuhn, T. S. (1962). *The Structure of Scientific Revolutions*. University of Chicago Press.
12. Lakatos, I. (1970). *Falsification and the methodology of scientific research programmes*. In I. Lakatos & A. Musgrave (Eds.), *Criticism and the Growth of Knowledge* (pp. 91–196). Cambridge University Press.
13. Landry, E., & Marquis, J.-P. (2005). *Categories in context: Historical, foundational, and philosophical*. In J. Earman & J. Norton (Eds.), *The Cambridge History of Philosophy of Science*. Cambridge University Press.
14. Mac Lane, S. (1971). *Categories for the Working Mathematician*. Springer.
15. Nersessian, N. (2008). *Creating Scientific Concepts*. MIT Press.
16. Popper, K. R. (1959). *The Logic of Scientific Discovery*. Hutchinson.
17. Reichenbach, H. (1938). *Experience and Prediction*. University of Chicago Press.
18. Spivak, D. I. (2014). *Category Theory for the Sciences*. MIT Press.
19. Suppe, F. (Ed.). (1977). *The Structure of Scientific Theories* (2nd ed.). University of Illinois Press.
20. van Fraassen, B. C. (1989). *Laws and Symmetry*. Oxford University Press.