The Interactive Aspect of Science

Abstract
Hempel, Popper, and Kuhn argue that to be scientific is to be testable, to be falsifiable, and most nearly to do normal science, respectively. I argue that to be scientific is largely to be interactive, offering some examples from science to show that the ideas from different fields of science interact with one another. The results of the interactions are that hypotheses become more plausible, new phenomena are explained and predicted, we understand phenomena from a new perspective, and our worldview becomes simpler. I also argue that given that the interactions are impressive features of science, astrology and religion would be regarded as science, provided that there are similar interactions in those enterprises.

Keywords
Falsifiable, Interactive, Nature of Science, Normal Science, Testable

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1. Introduction

What is the nature of science? This question is interesting in itself for those who want to know what science is. In addition, an answer to this question has an important practical implication. What we should teach to our school children in science classrooms depends on what we take to be what science is. Some people may argue that astrology and creation science are science like astronomy and biology, so they should also be taught in schools. Others may argue that they do not meet the standards of science, so they should not be taught in schools. The resolution of the dispute between the opposing camps requires a clear conception of what science is.

In general, there are three approaches to understand an object. I call them the historical approach, the functional approach, and the compositional approach. To put briefly, we investigate where an object came from, what it does, and what it is made up of in order to understand it. In the following sections, I expound the three different approaches and then apply the compositional approach to science. I introduce Carl Hempel, Karl Popper, and Thomas Kuhn's compositional definitions of science, and then present my own. This paper is intended to be useful not only to philosophers of science but also to policymakers who ought to make decisions on what we should teach in science classrooms.

2. Three Approaches

The historical approach is an attempt to understand an object by shedding light on where it came from. For example, what is human species? Evolutionists say that humans have evolved from single-celled organisms, whereas creationists say that God created them. Evolutionists and creationists disagree about the origin of human species but agree that we can understand human species by unveiling its history, especially its origin. Similarly, the big bang theory is an attempt to understand the universe by tracking its history, especially its origin. The theory holds that the universe, which was smaller than an atom, expanded approximately 14 billion years ago. The historical approach is built on the view that we cannot fully understand an object without knowing its history, especially its origin.

The functional approach is an attempt to understand an object by throwing light on what it does. For example, think of sundials, water clocks, and digital clocks (Schick and Vaughn, 2010: 125). They might have come from different factories, and they might be made up of different materials. Yet, they all belong to the same kind, viz., clocks, because they all perform the same function, viz., keeping time. What makes a clock what it is is what it does, not where it came from or what it is made up of. The same thing can be said of a gene. A gene is whatever is responsible for phenotypes and whatever conveys the hereditary information from parents to offspring. The functional approach is built on the view that we cannot fully understand an object without knowing what it does.

The compositional approach is an attempt to understand an object by casting light on what it is made up of. For example, what is water? Chemists say that water is H_2O. The essence of water lies in its chemical composition. In other words, what makes water what it is is what it is made up of. Presocratic philosophers in ancient Greece proposed various hypotheses about the fundamental building blocks of the universe (Jones, 1970). For examples, Thales, Anaximander, Pythagoras, and Democritus contended that everything is made out of water, boundless, numbers, and atoms, respectively. Their hope was to understand physical objects like trees, apples, stones, and so on by investigating their physical compositions. The compositional approach is built on the view that we cannot fully understand an object without knowing what it is made up of.

The preceding three approaches can be applied to science. We might take the historical approach, investigating the history of science, especially the origin of science. Thus, we might inquire into what Presocratics were doing, as Popper (1963, Chapter 5) suggests. According to Popper, Presocratics initiated science by being engaged in a series of conjectures and refutations over the basic stuff of the universe. We might take the functional approach, investigating what science does. We might, for example, explore the impacts of science on economy, on politics, culture, on art, on religion, on environment, on civilization, etc. This paper, however, takes neither the historical approach nor the functional approach to science due to lack of space. It takes only the compositional approach to science.

Science is composed of certain activities. The most salient ones are constructing hypotheses, observing the world, and performing experiments. Also, science is not an individualistic enterprise but a collaborative enterprise, as sociologists of science (Latour and Woolgar, 1986; Latour, 1987) aptly observe. Scientists hold a meeting to reach an agreement on whether a particular experimental result establishes a hypothesis or not. They attend conferences and publish papers where they criticize opponents' hypotheses and experiments, and defend their own hypotheses and experiments from their opponents' criticisms. In order to do these things, they use the research funds from governments, universities, and private industries.

This paper focuses on the scientific activities related to hypotheses. Scientists do not set up any hypotheses. Certain hypotheses count as scientific, whereas others do not. Consider the hypothesis that everything is the way it is because God made it so. Such hypotheses do not count as scientific, and hence it is inappropriate to teach them in schools. This attitude, however, triggers an interesting question: How do scientific hypotheses differ from nonscientific hypotheses, including religious ones? Some philosophers of science have already answered this question in the philosophy of science literature. Their answers, however, differ from one another. I summarize them and propose my own in the following section.

3. Scientific Hypotheses

3.1. Testability

Hempel (1966) proposes that to be scientific is to be testable. A scientific hypothesis is one that has a bearing on observations. We go through the following process to test a hypothesis: Assume that the hypothesis is true, we imagine what observable events would occur and would not occur. We observe the relevant part of the world. The hypothesis is confirmed and disconfirmed, respectively, if an observable event occurs that agrees with it, and if another observable event occurs that disagrees with it. Thus, the hypothesis passes or fails a test, depending on what observable event occurs. Hempel summarizes the point as follows:

> ..no statement or set of statements *T* can be significantly proposed as a scientific hypothesis or theory unless it is amenable to objective empirical test, at least "in principle." (Hempel, 1966: 30)

The ideal gas law, for example, states that PV=kT, where p is the pressure of the gas, V is the volume of the gas, k is a constant, and T is the temperature of the gas. We can test the ideal gas law as follows: We assume that the ideal gas law is true. We hold V constant, increase T, and then check whether P increases or decreases. The ideal gas law is confirmed and disconfirmed, respectively, if P increases and decreases.

Compare the ideal gas law with the following two hypotheses: (1) One ghost can stand on the tip of a needle. (2) Two ghosts can stand on the tip of a needle. Imagine that two people disagree over whether (1) or (2) is true. They agree, however, that a ghost is invisible, weightless, and tiny. One argues that (1) is true, so they need to sacrifice one goat for one ghost. The other argues that (2) is true, so they need to sacrifice two goats for two ghosts. They have a quarrel for a day, but they fail to reach an agreement. Hempel would say that neither (1) nor (2) is testable, i.e., neither (1) nor (2) has a bearing on observations. Therefore, none of them is scientific.

3.2. Falsifiability

Alfred Adler (1970-1937) founded a school of thought called individual psychology. Individual psychology holds that all human behavior is motivated by the feeling of inferiority. Popper (1963) objects that individual psychology remains unrefuted, no matter what happens. Imagine, for example, that a man pushes a child into a river. According to individual psychology, the man did so because he suffered from the feeling of inferiority and he wanted to prove to himself that he dared to commit a crime. Imagine now that the man rescued a drowning child in a river. According to individual psychology, he did so because he suffered from the feeling of inferiority and he wanted to prove to himself that he dared to rescue the child. Individual psychology is compatible with whatever the man does. We cannot even conceive of an observable event that would refute individual psychology.

Popper compares individual psychology with Albert Einstein's general theory of relativity. If the general theory of relativity is true, light would travel in a curved path near the sun, and hence we would be able to observe the change of apparent positions of stars during the solar eclipse. If the change of apparent positions of stars is not perceptible, the general theory of relativity would be refuted. Thus, the general theory of relativity is compatible with certain observable events but incompatible with other observable events. We can conceive of an observable event that would refute the general theory of relativity.

On Popper's view, to be scientific is to be falsifiable. A hypothesis is falsifiable if and only if we can conceive of an observable event that is incompatible with it. Thus, falsifiability is the criterion for distinguishing between scientific hypotheses and nonscientific hypotheses:

> The criterion of falsifiability is a solution to this problem of demarcation, for it says that statements or systems of statements, in order to be ranked as scientific, must be capable of conflicting with possible, or conceivable, observations. (Popper, 1963: 51)

Note that Popper invokes conceivable observations, not actual observations, to flesh out the notion of falsifiability. There is a huge difference between actual and conceivable observations. If a hypothesis conflicts with an actual observation, it is falsified. Past theories, such as the Ptolemaic theory, the phlogiston theory of combustion, and the caloric theory of heat were falsified because they conflicted with actual observations. In contrast, if a hypothesis conflicts with a conceivable observation, but not with an actual observation, it is not falsified but falsifiable.

Let me apply Popper's proposal to a tricky example. Consider the hypothesis that our universe collides with another universe. Many theoretical physicists today argue that there are many expanding universes, and that if our universe collides with another universe, the impact between the two universes "would send shock waves rippling through space, generating modifications to the pattern of hot and cold regions in the microwave background radiation" (Greene, 2011: 191). Unfortunately, scientists have not yet detected the modifications. Is this hypothesis falsifiable or not? Popper would say that it is falsifiable. After all, we can *conceive* of the situation in which no such modification occurs in our universe.

The hypothesis that our universe collides with another universe is different from the unfalsifiable hypotheses, such as the supernatural hypothesis that everything is the way it is because God made it so and Adler's individual psychology that all human behavior is motivated by the feeling of inferiority. We cannot even conceive of an observable event that conflicts with the supernatural hypothesis or individual psychology. Whatever observable event we might think up is compatible with them. Therefore, they are not falsifiable.

3.3. Normal Science

Kuhn contends that Popper's characterization of science applies to extraordinary science, but not to normal science. In other words, scientists attempt to falsify theories during the research period of extraordinary science, but not during the research period of normal science. Moreover, normal science "accounts for the overwhelming majority of the work done in basic science" (Kuhn, 1970: 4). On Kuhn's proposal, to be scientific is most nearly to do normal science:

> Finally, and this is for now my main point, a carefully look at the scientific enterprise suggests that it is normal science, in which Sir Karl's sort of testing does not occur, rather than extraordinary science which most nearly distinguishes science from other enterprises. (Kuhn, 1970: 6).

Normal science is what scientists do after a paradigm is established, and it is followed by extraordinary science. Thus, we need to be clear about the concepts of paradigm, normal science, and extraordinary science in order to understand Kuhn's definition of science.

A paradigm is "the entire constellation of beliefs, values, techniques and so on shared by the members of a given community" (Kuhn, 1962/1970: 175). For example, the Copernican paradigm and the Ptolemaic paradigm have different beliefs about the world. The former includes the belief that the earth moves around the sun, and the latter includes the belief that the earth is the center of the universe. The former takes it to be important to measure the speed of the earth, whereas the latter does not. Copernican scientists have the skill to use telescopes, but Ptolematic scientists do not. Once scientists successfully explain puzzling phenomena in terms of a new theory, a paradigm is established and normal science begins.

Normal scientists dogmatically hang onto a paradigm. Without questioning the paradigm, they are engaged in puzzle-solving activities. To solve puzzles is to apply a paradigm to various parts of the world, to articulate the paradigm, to devise mathematical techniques, to improving scientific instruments, and so on. If a scientist fails to solve a puzzle, blame is put not on the paradigm but on the scientist. In other words, if an experimental result conflicts with a paradigm, normal scientists think that it is the experimental result, not the paradigm, that should be thrown out. As they apply the paradigm to various parts of the world, they encounter phenomena which cannot be accommodated by the paradigm. Such phenomena are called anomalies.

The accumulation of serious anomalies leads scientists to lose confidence on the paradigm, and scientists start doing extraordinary science. Extraordinary scientists question their paradigm. They are no longer engaged in solving puzzles. Rather, they ask philosophical questions about the world, and they think up a new paradigm. The new paradigm is incompatible with the old one. They postulate different theoretical entities, and they pose different questions about the world. Finally, the old paradigm is abandoned, and the new paradigm is adopted.

On Kuhn's account, astronomy is science but astrology is not because astronomers solve puzzles, but astrologers do not. Ptolemaic astronomers were solving puzzles when they fiddled with epicycles, eccentrics, and equants. The mismatch between the Ptolemaic theory and the motions of planets was a puzzle they had to solve. They were revising the Ptolemaic theory so that it might fit the motions of planets. In contrast, astrology was not in the business of solving puzzles:

> The astrologer, by contrast, had no such puzzles. The occurrence of failures could be explained, but particular failures did not give rise to research puzzles, for no man, however skilled, could make use of them in a constructive attempt to revise the astrological tradition. (Kuhn, 1970: 9)

When astrologers made false predictions about a person's fate, they did not attempt to revise astrological hypotheses. They thought that their failures to make true predictions did not constitute puzzles they should solve. Since they did not solve puzzles, their enterprise does not account as science.

What are we to make of Kuhn's account of science? Several criticisms can be leveled at it. My criticism is that it is silent about interdisciplinary research and education in science. As we will see in the following section, the ideas from different fields of science interact with one another. Scientists belonging to different paradigms cooperate with one another to solve a common problem. It is not clear how Kuhn's account of science can handle this interactive aspect of science.

3.4. Interaction

Let me advance a slogan that captures an important aspect of science, viz., to be scientific is largely to be interactive. It is ubiquitous phenomena at least in contemporary science that the ideas from different fields of science interact with one another. As a result, hypotheses become more plausible, new phenomena are explained and predicted, we come to understand phenomena from a new perspective, and our worldview becomes simpler. I introduce the following five ways, which are not intended to be exhaustive, in which ideas interact with one another in science:

First, scientists today take into account the research achievements of neighboring fields when they set up hypotheses in their own fields. For example, physicists developed the radiometric dating technique at the end of 19^{th} century. The technique enables us to determine how old material objects are. Geologists make use of the technique when they construct hypotheses about distant pasts. Seungbae Park (2011: 80-82) calls this phenomenon neighbor constraint. The idea is that the research achievements of a field of science impose constraints on the hypothesis constructions of neighboring fields of science. A geological hypothesis born with the neighbor constraint of the radiometric dating technique is more plausible than a competing hypothesis born without the constraint. It is for this reason that the hypothesis that the earth is about 4.5 billion years old is more likely to be true than the hypothesis that it is six thousand years old.

Second, as Michael Friedman (1981) observes, theories from different fields of science jointly predict and explain new phenomena. For example, evolutionary theory claims that marsupials flourished in South America millions of years ago. The theory of plate tectonics claims that South America, Antarctica, and Australia once formed a giant continent called Gondwanaland, and they drifted apart millions of years ago. Aware of these two theories, scientists speculated for years that marsupials migrated from South America to Australia via Antarctica, and inferred that there are marsupial fossils in Antarctica. A group of scientists discovered the marsupial fossils in Antarctica (Woodburne and Zinsmeister, 1982). Note that neither the biological theory nor the geological theory alone can explain the existence of marsupial fossils in Antarctica. Their existence can only be explained by the cooperation of the two theories.

Third, there is an incessant quest for unification in science. The intuitive idea of unification is that X and Y appear to be different kinds of objects, but on close examination, they are just different manifestations of the same kind of objects. For example, water and fire appear to be different kinds of objects. But atomism tells us that they are just different collections of the same kind of things, viz., atoms. Thus, atomism unified water and fire. Once objects are unified, our worldview becomes simpler. The worldview that there are atoms and empty space is simpler than the worldview that there are water, fire, trees, stones, and so forth. What get unified in science are not only objects but also theories, laws, phenomena, and forces. Newton's theory of motion unified Galileo Galilei's law of freefall and Johannes Kepler's three laws of planetary motion, explaining both the motions of terrestrial objects and the motions of planets. Theoretical physicists today proposed string theory to unify quantum mechanics and the general theory of relativity, claiming that electromagnetic force, strong force, weak force, and gravitational force are all just different manifestations of a single fundamental force. Again, unification yields a simplified picture of the universe.

Fourth, scientists not only come up with original ideas but also combine different original ideas so that the combination of the different ideas may work as a packet. For example, the law of inertia is not original with Newton. It was discovered by Galileo and formulated by René Descartes. Newton combined the law of inertia with his second law of motion, the third law of motion, and the law of gravity. These four laws of nature work together, i.e., they constitute a theory explaining and predicting the motions of bodies. For another example, evolutionary theory consists of the two big ideas: the tree of life and the principle of natural selection. Neither the tree of life nor the principle of natural selection was original with Darwin. The tree of life can be traced back to Augustin Augier and Jean-Baptiste Lamarck who published the tree of plants in 1801 and the tree of animals in 1809, respectively. The principle of natural selection can be traced back as far as to the ancient Greek philosopher, Empedocles, who claimed that “various body parts combined and those that were best able to function survived” (Everson, 2007: 5). What Darwin did was to graft the tree of life and the principle of natural selection and to use them to explain biological phenomena (Sober, 1993: 7). He initiated a new explanatory scheme, and hence a new paradigm in biology. When different ideas are combined and jointly explain phenomena, we come to understand phenomena from a new perspective.

Fifth, scientists of different fields do research independently of one another, but their research results miraculously fit together. Let me use a controversial example. Some theoretical physicists accept but other theoretical physicists reject the multiverse hypothesis according to which there are an infinite number of universes. In some of those universes, there are people who look exactly like you. In others of those universes, physical features are radically different from those of our universe, and hence there are no such things as the earth, the solar system, and galaxies. The support for the multiverse hypothesis has come surprisingly from many independent researches (Greene, 2011). Let me introduce following three of them:

The first support has come from the research concerning eternal inflation. Allen Guth (1981) came up with the inflationary hypothesis that our universe, which was smaller than an atom, expanded to the size much larger than the currently observable part of the universe in a tiny fraction of a second about 14 billion years ago. The inflationary hypothesis explains why the temperature, which is 2.725 above absolute zero, is uniform across space. Guth’s hypothesis led Alex Vilenkin (1983) and Andrei Linde (1983) to the hypothesis of eternal inflation according to which big bangs occur numerous times, i.e., countless universes are created. The hypothesis predicted that there would be temperature variations ranging from 2.7245K to 2.7255K, and the actual measurements agree with the prediction. The hypothesis of eternal inflation goes along with the multiverse hypothesis.

The second support has come from the research concerning dark energy. Astronomers discovered that the expansion of our universe is not slowing down but speeding up. The accelerating expansion is mysterious, given that gravitational pull among galaxies should reduce the expansion rate. Astronomers postulated the existence of dark energy to explain the accelerating expansion of the universe. Dark energy behaves like Einstein’s cosmological constant. Scientists measured the cosmological constant, and it turns out to be 10^{-122} in Plank units (Barrow and Shaw, 2011). Brian Greene (2011: 146) argues that this value goes well with the multiverse hypothesis. The idea is that if there are an infinite number of universes, it is natural that the cosmological constant is extremely close to zero in some universes. Our universe happens to be one of them.

The third support has come from the research concerning string theory. String theory claims that everything is made out of tiny vibrating strands or loops of energy called strings. All the microscopic particles, such as electrons, quarks, and photons, are made out of strings. Strings become different particles, depending on how they vibrate. String theory requires that strings vibrate in extra dimensions of space. Every point in space is curled up with extra dimensions of space, and the shape of those extra dimensions determines how strings vibrate, and the vibration patterns determine how the universe behaves. Therefore, the way the extra dimensions are put together determine the fundamental features of the universe. It transpires that there are an astronomical number of different possible shapes of extra dimensions. This number meshes well with the multiverse hypothesis because each shape of extra dimensions represents each universe of multiverse (Susskind, 2003; Szabo, 2004).

The hypothesis of eternal inflation, the hypothesis of dark energy, and string theory get connected with one another via the multiverse hypothesis. The three independent research results concerning eternal inflation, dark energy, and extra dimensions converge on the multiverse hypothesis that there are an infinite number of universes (Greene, 2011: 9-10). The convergence here does not mean that the multiverse hypothesis unifies the hypothesis of eternal inflation, the hypothesis of dark energy, and string theory. Nor does it mean that the multiverse hypothesis is proved to be true. It simply means that the three independent research results jointly support the multiverse hypothesis, and that they are more plausible than they would if they stood alone. The multiverse hypothesis has an indirect bearing on observables, i.e., it is related to observables via the three independent research results which are somehow connected with observables. If the three independent research results collapse, so would the multiverse hypothesis. Thus, the multiverse hypothesis is more than a speculative assumption, an assumption that has no bearing on observables.

One may object that the hypothesis of dark energy, the hypothesis of eternal inflation, and string theory are all from the same field of science, viz., theoretical physics. So this example does not fit my thesis that hypotheses from various fields of science interact with one another in contemporary science. I reply that theoretical physics consists of different subfields, such as cosmology and particle physics, the hypothesis of dark energy is from both cosmology and astronomy, the hypothesis of eternal inflation is from cosmology, and string theory is from particle physics. So this example by and large fits my thesis.

So far I argued that in science, a research achievement of a field puts a neighbor constraint on the hypothesis construction of a neighboring field, hypotheses from different fields jointly predict and explain new phenomena, there is a ceaseless quest for unification, different ideas are grafted with one another to form a packet, and independent research results dovetail with each other. Given that these interactive features are the impressive features of science that hold people in awe, I propose that if astrology and religion have these features, they would undoubtedly be science just like physics, biology, and geology. Specifically, Christianity, Buddhism, and Islam would be science, provided that they impose neighbor constraints on one another, they jointly explain new phenomena, they attempt to unify the disparate laws of nature discovered in their own fields with a more fundamental law of nature, and different ideas from the religions form a packet, and independent research results of the religions converge on the same hypothesis. I leave the task of exhibiting these interactive features to astrologers and theists.

I agree with Kuhn (1970) that there is no clear demarcation between science and non-science. But I must say that there are typical scientific activities, and that the more an enterprise shows the typical scientific activities, the more scientific it is. The interactions of ideas from different fields of science are more typical and pervasive phenomena in present science than in past science. In present science, interdisciplinary research and education are encouraged, facilitating the communications between different fields of science. Some readers might think that the number of examples of interaction provided in this paper is too small. Let me bring their attention to Trefil and Hazen (2012). This book offers many examples, demonstrating just how prevalent the interactions of ideas are in contemporary science.

The interactive aspect of science is an anomaly to Kuhn's account of science. Theoretical physicists, for example, are doing neither normal science nor extraordinary science when they attempt to unify quantum mechanics and the general theory of relativity. It is wrong to say that they are doing normal science within a paradigm because it is not clear whether unifying the two paradigms counts as a puzzle-solving activity. Kuhn (1962/1970) does not say anything about unifying two paradigms. It is also wrong to say that the theoretical physicists are doing extraordinary science because they do not aim to falsify quantum mechanics or the general theory of relativity. The unification of these two paradigms does not mean that both of them or one of them is falsified. It would rather mean that they are subsumed under a more fundamental paradigm.

Kuhn might reply that the theoretical physicists are solving a puzzle, viz., getting rid of an internal inconsistency within the grand paradigm, viz., physics. They all belong to the same grand paradigm. A problem with this move, however, is that the notion of paradigm would become intractable. After all, it might be argued that Ptolemaic astronomers and Copernican astronomers also belonged to the same grand paradigm, viz., astronomy. Kuhn's original thesis that competing paradigms, such as the Ptolemaic paradigm and the Copernican paradigm, are incommensurable would collapse. After all, the Ptolemaic paradigm and the Copernican paradigm would merely be different components of the same grand paradigm, viz., astronomy, and hence they should be commensurable. To go further, science and religion would also be merely different components of the same grand paradigm, viz., the human intellectual endeavor. 'Paradigm' would cease to be a useful predicate.

4. Conclusion

Hempel, Popper, and Kuhn argue that to be scientific is to be testable, to be falsifiable, and most nearly to do normal science, respectively. I argued that to be scientific is largely to be interactive. I do not claim that Hempel's, Popper's, and Kuhn's accounts of science capture no aspect of science. After all, they are supported by their examples, just as my account is supported by my examples from science. Hempel's account, Popper's account, and Kuhn's account capture the aspects of science, respectively, that a hypothesis explains and predicts phenomena, a hypothesis is thrown out, and a hypothesis is adhered to. My account captures the aspect of science that different ideas interact with one another. My conclusion is that science has multiple facets, calling for multiple accounts.

My conclusion has important implications on science education. First, the more an enterprise shows the aforesaid multiple aspects of science, the more scientific it is, and hence the more convincing it becomes that the enterprise deserves a place in science education. Second, if science teachers aim to unveil the nature of science to their students, they should help students see the aforementioned multiple facets of science. They should display the typical cases in which a hypothesis is tested, falsified, adhered to, and interacts with other hypotheses. Students will obtain a more complete picture of science, if they are exposed to all those facets of science than they would if they were exposed to only some of them. Finally, let me emphasize that students should know how the ideas from different fields of science interact with one another, given that we now live in the era when multidisciplinary research and education are encouraged to scientists.

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