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Error and the Progress of Science: An Analysis of the Philosophies of Karl Popper and Paul Feyerabend

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Abstract:
This article examines the epistemological role of scientific error by analyzing the responses of Karl Popper and Paul Feyerabend to the problem of error. It begins by clarifying the terminological foundations for the use of the term error in scientific contexts. Popper's response is then discussed within the framework of falsifiability, emphasizing how his conception of conjectures and refutations departs from traditional views, while still presenting certain limitations. Feyerabend's progressive response, in turn, attributes an essential and non-transitory role to error in the advancement of knowledge, particularly within the divergent proliferation of cosmologies. By critically examining this response, the article contributes to a broader understanding of the significance of errors in scientific progress.

Keywords: Cosmological pluralism; Falsifiability; Karl Popper; Paul Feyerabend; Scientific error

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Introduction

When it comes to errors, it is understood that a generalization of episodes of scientific errors can be used to undermine public confidence in scientific knowledge. Information that highlights the fallibility of science – such as the replacement of theories, experimental changes, or lack of consensus on certain theories – is often presented in schools, universities, or the media in a superficial manner. This neglects the relevance of errors to the development

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of scientific knowledge and contributes to public distrust and skepticism towards science (Allchin 2020).

Therefore, it is necessary to provide students and the general public with a better understanding of the relationship between errors and science, helping them to evaluate errors not as threats but as an integral part of scientific development and how it operates within science. To achieve this, a philosophical foundation is required that offers a critical understanding of the role of errors in scientific knowledge.

The recognition that all of us make mistakes and that science, as a human endeavor, inevitably contains errors is now widely accepted in the philosophy of science. Nevertheless, despite this consensus, the topic of scientific errors remains secondary compared to the focus of most philosophical investigations on scientific successes (Rescher 2007). In this sense, the subject of scientific error still lacks studies that expand our understanding of its role in the progress of scientific knowledge.

The challenge faced by the philosophy of science explaining how we learn about the world in the presence of errors has generated responses that can be categorized as either *traditionalist* or *progressivist* (Oliveira and Queiroz 2021). Within this framework, this article aims to explore the progressivist responses of Karl Popper and Paul Feyerabend regarding error and the advancement of scientific knowledge. It seeks to outline the basic principles underlying each philosopher's perspective in order to clarify the fundamental agreements and disagreements between their critical philosophies.

A traditionalist view of error, as found in the philosophies of, for example, Francis Bacon, René Descartes, regards error as something to which humans are susceptible but that can, in principle, be prevented and eliminated from the processes and results of scientific knowledge (Oliveira and Queiroz 2021; Miller 1985).

At the other end of this spectrum, a progressivist view, such as that found in the philosophies of Popper, Allchin, and Feyerabend (Oliveira and Queiroz 2021; Miller 1985), considers error to be inherent to science. Consequently, we cannot be certain of achieving error-free knowledge but instead rely on learning from errors. As Oliveira and Queiroz stated "more one supports the possibility of total removability of errors from the process of building scientific knowledge, the more traditional he/she will probably be" (2021, 78).

Although it is widely recognized that Popper and his critical rationalism have played a significant role in discussions about error, particularly in relation to trial and error, fundamental questions such as what constitutes an error and how it relates to scientific progress still require deeper investigation.

On the other hand, there has been little debate about the concept of error among Feyerabendian scholars. This is partly because Feyerabend never dedicated a specific article exclusively to this subject. However, this lack of direct focus does not mean that Feyerabend failed to make valuable contributions to the issue of error. Since the 1970s, he has raised dynamic and cutting-edge questions. Moreover, the way error has been underestimated and reduced to merely one stage of the scientific process has often been challenged by Feyerabend (Oliveira and Queiroz 2021).

We begin by examining the linguistic and etymological meaning of the word *error*. From this foundation, this paper investigates progressive responses concerning the role of error in the advancement of knowledge, focusing on Popper's falsifiability and Feyerabend's divergent cosmological pluralism as argued by Oliveira (2021).[3]

[3] According to Oliveira (2021, 424), Feyerabend's notion of cosmological pluralism refers to cosmological theories understood as theories "rooted in an ontological dimension, bringing up all kinds of implications to every aspect of our realities and forms of knowledge".

On the Meaning of Error: A Distinction Between Deviation and Mistake

The expression "*scientific errors*" presents a challenge for research on the subject, partly due to the complexity of the term itself and partly due to the rigidity that a strict definition may impose, risking the loss of meaning over time and across different contexts. Nevertheless, it is necessary to establish some distinctions regarding the synonyms of the word *error* and to define a basic premise for the discussions surrounding scientific errors.

The term *error* has been employed by several philosophers in addressing scientific mistakes. Philosophers such as Popper, Feyerabend, and Allchin frequently use the word *error* in their works, albeit from different philosophical perspectives. For this reason, it is important to clarify the basis behind the choices of this term.

The word "*error*" in most Indo-European languages originally meant "*to wander*" or "*to stray from the path*". In Latin, it derives from *errare,* which can be defined as to "wander", "to stray", "to go off course", "to roam", as well as "doubt" or "uncertainty". The figurative meaning of "going astray" or "making a mistake" no longer refers to a physical deviation but rather to a deviation from the proper course of thought or action.

When we examine these meanings, two semantic axes become especially prominent: *mistake*, associated with wandering, doubt, and uncertainty; and *deviation*, associated with straying and going off course.

Deviation refers to the act of moving away from an established course or an accepted standard. The Latin roots of the word *error* encompass meanings such as "*deviation from the correct path or direction*" as well as "*error*" in the sense of "*morally questionable behavior*". In English, *error* also carries the meaning of "*a deviation from accuracy or correctness*", for instance, *an error in action or speech*, or *a condition of deviation from precision* (according to the *Thesaurus Dictionary* in American English), or "*a deviation from correctness in belief, action, or speech*" (according to the *Collins Dictionary*[4] in British English). Thus, *error as deviation* refers to a departure from a standard or an accepted norm.

This notion of *error as deviation*, as we will discuss in the following sections, can be examined through the perspectives of Feyerabend (1981/1970; 1993) and Popper (1959; 2002/1963).

Additionally, in relation to *deviation*, *error* can refer to a deviation from a religious belief or moral standard, a moral offense, wrongdoing, or sin, essentially a violation of ethical norms (as defined in the *Thesaurus* and *Collins* dictionaries in both American and British English).

At certain points, *error* can be synonymous with *mistake*, particularly when referring to inaccuracies in actions, speech, calculations, opinions, or judgments that result from faulty reasoning, carelessness, or insufficient knowledge. It can also refer to typographical mistakes or failures to correctly understand, interpret, or evaluate something, essentially misunderstandings or misconceptions (as defined in both the *Thesaurus* and *Collins* dictionaries). This interpretation appears in several passages of Popper's work *Conjectures and Refutations* (2002/1963). On the other hand, *mistake* can also refer merely to confusion or misunderstanding, often without deeper epistemological implications.

Some may attempt to compare "*error*" to "*false*", but *false* is an adjective meaning "*not true*" or "*incorrect*" –, for example, *a false statement.* It refers to declaring something that is not true, whether based on mistaken, erroneous, or inconsistent impressions, ideas, or facts. In other words, when we say that *X is false*, we are stating that *X is not true.* However, declaring *X to be true when it is actually false* constitutes an *error* – either due to a misunderstanding (*mistake*) or a *deviation* from an accepted standard of judgment.

[4] See: http://www.collinsdictionary.com.

Therefore, the two main concepts discussed here (*deviation* and *mistake*) can both represent meanings of *error.* However, in the context of science, these terms can be distinguished according to their usage: on one hand, *mistake* refers to simple misunderstandings or errors that can occur in any context, while the term *error* aligns more closely with *deviation*, since science operates within frameworks of comparison and established criteria. When something deviates from what is expected according to these standards, it is regarded as an *error.* As Abbagnano explains: "In general, any judgment or evaluation that contradicts criteria recognized as valid in the field to which the judgment refers, or the limits of applicability of the criteria itself, can be called an *error*" (Abbagnano 2004, 341, author's translation).

Following this perspective, referring to scientific errors does not merely involve simple mistakes or misunderstandings, although such mistakes do occur, particularly at lower levels of scientific activity or during experimental work.

This leads to the question: What defines a scientific error? This question, in some ways, invites authoritarian or prescriptive answers, similar to the traditional question, "What is science?". Since defining science is not the purpose of this paper, we propose reframing the question into more productive inquiries such as: What are the different perspectives on scientific errors? Are there reliable sources or methods that can completely prevent the occurrence of errors? Is it possible to achieve scientific progress despite the presence of errors? Must errors be eliminated before progress can occur?

The answers to these questions shape our understanding of errors. In the following sections, we will explore how some of the most prominent philosophers of science have approached the concept of scientific error.

Popper's and Feyerabend's Responses to the Problem of Error

The quest to explain the growth of knowledge has come to dominate philosophical discussions, often sidelining the errors that occur throughout the process. However, the issue of error implicitly underlies any explanation of knowledge, since there can be no success without the occurrence of mistakes along the way.

Philosophers' responses to the challenge of explaining progress in the presence of error can be broadly divided into traditionalist and progressive approaches, although these positions form a spectrum rather than two strictly separated categories (Oliveira and Queiroz 2021, 78). On one hand, traditionalists such as Francis Bacon and René Descartes[5] believe that it is possible to eliminate error from the development of scientific knowledge. On the other

[5] Bacon and Descartes represent a more traditionalist response to error and, within the history of Western philosophy of science, are recognized as the earliest and most prominent figures of this view. However, Oliveira and Queiroz (2021) point out that philosophers such as Gaston Bachelard do not break with this framework; rather, his stretch and reorient it, moving toward a more progressivist stance. Bachelard's notion of epistemological obstacles conceives errors as cognitive barriers derived from prior knowledge – barriers that must be recognized and overcome for scientific progress to occur. For Bachelard, errors are fundamental to advancement: they are not to be avoided in advance but rectified. Scientific knowledge is inherently transformative and historical ("there is no truth without rectification" [Bachelard 1996: 293, author's translation]), which brings Bachelard closer to progressivist perspectives.

This intermediate and conceptually dense position, although it preserves traditional elements – such as the idea of rational and disciplined progress – also clearly emphasizes the role of errors as driving forces of scientific development, which aligns it with contemporary progressivist perspectives. This nuanced position warrants deeper examination, which lies beyond the scope of this article and will be developed in future work.

hand, progressives argue that the complete elimination of the possibility of error is not achievable.

For Bacon, the "idols and false notions which have already preoccupied the human understanding" (Bacon 2003/1620, I: XXXVIII) produce "the anticipation of nature (as being rash and premature)" and, consequently, *deviations* in the correct "interpretation of nature" (Bacon 2003/1620, I: XXVI). These idols obstruct truth and create barriers to scientific inquiry. Essentially, Bacon's conception of error implies that it is a product of human nature, originated from idols or false notions that arise naturally in the human mind and deviate from the pattern found in nature: "the sole cause and root of almost every defect in the sciences is this, that while we falsely admire and extol the powers of the human mind, we do not search for its real helps" (Bacon 2003/1620, I: IX).

Although idols are part of human nature, they can be eliminated through the inductive method, thereby preventing and extinguishing the possibility of error. In this perspective, errors are natural but avoidable. Thus, for Bacon, progress cannot occur without the purification of prejudices and predispositions; only after this cleansing would we be on the path to truth, and on this path, errors would not occur, since we would be following an infallible method, freed of idols (Bacon 2003/1620).

Bacon established a standard method for eliminating hypotheses and competing explanations through instances of the cross: "by which means the question is decided, and the first is received as the cause, while the other is dismissed and rejected" (Bacon 2003/1620, II: XXXVI). According to Bacon, when two hypotheses attempt to explain the same phenomenon, a decision must be made as to which one is the true hypothesis.

For Bacon, eliminating errors/idols was a possible task through the use of his method, because "all the perceptions, both of the senses and of the mind, bear reference to man and not to the universe" (Bacon 2003/1620, I: XLI). From this understanding, progress for Bacon occurs through the purging of errors, and in the dispute between theories, the true inductive method should be followed to eliminate incorrect theories, as there exists only one true knowledge (Bacon 2003/1620).

Another representative of the traditionalist view, Descartes (2000/1637) likewise acknowledges the fallibility inherent in human cognition. Whereas for Bacon such fallibility stems from distortions internal to human understanding,[6] for Descartes it derives, as it will be examined below, from the structural limitation of the human mind in distinguishing truth from error. Despite this difference in emphasis, Descartes maintains a similar confidence in the possibility of overcoming error through the proper application of scientific method.

In his argument, Descartes maintains that God, being a good being, did not implant in humans any inherent tendency to error, for doing so would mean attributing evil to human nature. In other words, nothing in humans is so flawed as to necessarily lead them into error. Errors come from the ignorance to which humans are exposed, as it is made explicit in the following passage. It is not necessary that "God should have given me a faculty expressly for this end, but that my being deceived arises from the circumstance that the power which God has given me of discerning truth from error is not infinite" (Descartes 1901, 50).

Thus, error involves the limitation of the human capacity to judge between true and false, since this instance of truth is real, exists, and is fully known by God. It is up to humans to exercise discernment to distinguish what is true from what is not. Moreover, in Descartes' view, there is no place for provisional theories; one must always seek the fundamental truth (Descartes 1901).

The method that enables the distinction between truthfulness and falsehood, and thus the elimination of error, consists of certain deduction or clear and evident intuition, starting

[6] "The human understanding is like a false mirror, which, receiving rays irregularly, distorts and discolours the nature of things by mingling its own nature with it" (Bacon 2003/1620, I: XLI).

from simple and reliable rules that gradually increase to the knowledge of all things. According to Descartes (2000/1637), this method reveals some self-evident truths, such as the *Cogito, ergo sum*, which are completely error-free and serve as the foundation for scientific knowledge, liberating us from the errors of the senses.

Therefore, it is evident that the traditionalist view conceives errors as autonomous instances that can be identified and eliminated by science through its methods, as their presence is seen as counterproductive and negative. There is no room for competing theories; only one true theory exists, meaning that no error can reside in true knowledge.

These traditional doctrines, primarily represented by Bacon and Descartes, have continued to influence the understanding of error in the history of the philosophy of science. Clearly, the traditionalist view that errors stem from human fallibility and are undesirable has led to disastrous consequences for how error is understood today. As a result, errors are still often seen as obstacles or negative elements and have been attacked in philosophical debates (Rescher 2007).

Moreover, the issue of error holds little relevance compared to the emphasis placed on the origins and pursuit of knowledge to explain scientific success. When present in philosophical debate, the topic is usually confined to the prevention or elimination of error (Oliveira and Queiroz 2021; Miller 1985).

This means that contemporary philosophers have inherited the challenge of explaining the progress of knowledge in the presence of error as an integral aspect of human understanding. With this in mind, we now turn to the responses of two major philosophers of science: Popper[7] and Feyerabend.

Error, Fallibilism, and the Pursuit of Verisimilitude in Popperian Philosophy

Popper's response to the problem of errors differs from the traditional view regarding the search for a method as a formula to prevent errors. For Popper, "that in the realm of errors *cure* is more important than prevention forms the gist of the philosophy of human knowledge known as critical rationalism" (Miller 1985, 10, emphasis added). This Popperian thesis on errors was systematized in his work *Conjectures and Refutations* (2002/1963), where he says that

> the doctrine of fallibility should not be regarded as part of a pessimistic epistemology. This doctrine implies that we may seek for truth, for objective truth, though more often than not we may miss it by a wide margin. And it implies that if we respect truth, we must search for it by persistently searching for our errors: by indefatigable rational criticism, and self-criticism. (Popper 2002/1963, 21)

As seen above, the Popperian thesis on errors is based on the following principles: [a] Errors are part of human fallibility; [b] We can pursue objective truth.

Obviously, [a] "errors are part of human fallibility" represents Popper's falsifiability position, in contrast to the doctrines of Bacon and Descartes, who divided knowledge into human and superhuman parts. It is precisely in the human part that, according to the

[7] It is important to acknowledge that Lakatos's reformulation of falsifiability, through his methodology of scientific research programmes, offers an alternative, and potentially more robust, framework for addressing the role of error in science. However, given the limitations of scope and the article's strict focus on the Popperian conception, an examination of Lakatos's contribution will not be undertaken here. The relevance of this approach nevertheless points to a promising direction for future work seeking to extend the discussion into the post-Popperian context.

traditional views of Bacon and Descartes, lies the refusal to recognize an evident truth reached by the superhuman part, represented by the senses or reason, respectively. Therefore, the human component would be the source of fallible opinions, errors, and ignorance.

According to Popper (2002/1963), the difference between error and ignorance lies in the fact that ignorance is a lack of knowledge, whereas error constitutes an obstacle in the pursuit of knowledge. On the other hand, in *Conjectures and Refutations* he says that

> Descartes and Spinoza went even further, and asserted that not only ignorance but also error is "something negative" a "privation" of knowledge, and even of the proper use of our freedom, as the work of some mischievous power, the source of impure and evil influences which pervert and poison our minds and instill in us the habit of resistance to knowledge. (Popper 2002/1963, 4)

Thus, in the traditionalist view, accordingly Miller (1985): "we should be ashamed of our mistakes, and should regret making them, since they must be the result of our incompetence or our lack of mature insight" (Miller 1985, 9).

In contrast, Popperian philosophy seeks to break with traditional conceptions of certainty, conceiving both errors and successes as part of the process in the pursuit of knowledge. Following this fallibilist and, to some extent, more progressive line, the author admits that scientific knowledge is entirely human and fallible.[8]

This internal fallibilist perspective of Popper can be understood as a response to the dilemmas arising from the debate against the ideal of justificationism and the verificationist thinking of inductive verification.

By rejecting the inductive method, Popper proposes as an alternative the hypothetico-deductive method, in which, through a new conjectural idea, conclusions can be logically deduced and subjected to tests, leading to a decision on whether the theory should be refuted or corroborated by empirical applications. Thus, "if the singular conclusions turn out to be acceptable, or verified, then we have found no reason to discard it. But if the decision is negative, falsified, then their falsification also falsifies the theory from which they were logically deduced" (Popper 1959, 10).

In this way "by means of empirical tests, in a negative sense: it must be possible for an empirical scientific system to be refuted by experience" (Popper 1959, 19). With this method, Popper's falsifiability establishes itself as a demarcation criterion between scientific and non-scientific statements.

In this demarcation, the criterion of falsifiability is also used to define a theory as wrong from the outset, that is, theories that need not even be tested against experience because they exhibit an uncontrollable or incorrigible type of error and should be avoided even before being investigated (Miller 1985). This stage of defining errors is a preliminary phase to the method and is the only way Popper admits to the prevention of errors.

Once the process of attempting to falsify a theory begins through the hypothetico-deductive method, and the theory under investigation is considered scientific (i.e., experimental or falsifiable), a second criterion must be used to find errors: the criterion of obscurity. According to Popper, something obscure in a theory indicates the presence of errors. He says:

[8] Popper clarifies that his fallibilist position is based on the doctrine of human fallibility: "which Nicolas of Cusa and Erasmus of Rotterdam (who refers to Socrates) revived; and it was this 'humanist' doctrine (in contradistinction to the optimistic doctrine on which Milton relied, the doctrine that truth will prevail) which Nicolas and Erasmus, Montaigne and Locke and Voltaire, followed by John Stuart Mill and Bertrand Russell, made the basis of the doctrine of tolerance" (Popper 2002/1963, 22).

> But we do possess criteria which, if *we are lucky*, may allow us to recognize error and falsity. Clarity and distinctness are not criteria of truth, but such things as obscurity or confusion *may* indicate error. Similarly, coherence cannot establish truth, but incoherence and inconsistency do establish falsehood. And, when they are recognized, our own errors provide the dim red lights which help us in groping our way out of the darkness of our cave (Popper 2002/1963, 37).

Clarity, whether derived from reason or observation, can be misleading for Popper, while what is obscure helps us identify the presence of errors. From this, we understand that errors are internal, logical, and conceptual issues within a theory must be identified and investigated through his method to determine whether the theory is false.[9] This happens when, through experiences and/or observations, we find evidence or examples contrary to what the theory asserts. Thus, for Popper, errors/deviations within a theory emerge through its critical comparison with empirical reality.

Learning lies in knowing what is wrong. Therefore, we can learn from errors by avoiding investigative efforts on theories containing incorrigible (non-falsifiable) errors, while in scientific theories, even obscurities can point to errors that lead to experimentation. These experiments allow the theory to be confronted with facts in order to falsify it.

We can see Popper's attempt to define a criterion that diverges from the Cartesian criterion of clarity and evidence to prevent the possibility of error. However, what Popper does is merely invert the problem without solving it: if we cannot define what is clear, how can we define what is obscure?

Moreover, Popper introduces a shift in focus – from positive to negative – in the pursuit of falsifying a theory. He argues that even in trying to falsify a theory, there is a possibility of getting closer to the truth. This refers to the other side of the response to the problem of error: [b] We can pursue objective truth – that is, scientific realism: "For the fact is that we too see science as the search for truth, and that, at least since Tarski, we are no longer afraid to say so. Indeed, it is only with respect to this aim, the discovery of truth" (Popper 2002/1963, 310).

What Popper aimed to show is that truth is beyond our reach, but that should not prevent us from pursuing it and being inspired by objective truth. For this, Popper introduces the concept of *verisimilitude*, which shares the same objective and regulative ideal character as the idea of objective or absolute truth. He says: "In Tarski's terminology, it is obviously a 'semantic' idea, like truth, or like logical consequence, and, therefore, content" (Popper 2002/1963, 317).

Truth is not the only goal of science, but also a truth with explanatory power, in the sense of being logically probable. In other words, scientific theories approach the truth when they contain a high degree of falsifiability, since "its empirical content, increases with its degree of falsifiability" (Popper 1959, 96).

This principle of objective truth is an essential part of Popper's view on errors. He clarifies that the way to approach truth is by learning from errors. Here we reach a consequence of his thesis: the search for our errors, their identification and elimination, ensures scientific progress. As the author states: "But science is one of the very few human activities – perhaps the only one – in which errors are systematically criticized and fairly often, in time, corrected" (Miller 1985, 172).

Progress in Popper represents an advance in relation to previous theories, and to know whether we are advancing in knowledge, we can compare competing theories. A new theory

[9] This distinction reinforces the definition of "false" presented in our section above titled "On the meaning of error", as "false" is an adjective that refers to a statement that is not true, uttered or declared based on mistaken, erroneous, or inconsistent impressions, ideas, or facts.

must present greater empirical content and, therefore, be more falsifiable or refutable than the prevailing theory. In other words, "which is logically stronger; which has the greater explanatory and predictive power; and which can therefore be more severely tested by comparing predicted facts with observations" (Miller 1985, 173). This alone saves effort and, as noted earlier, avoids incorrigible errors.

From this criterion, it is possible to observe an evolution, compared to the evolutionary theory of species through natural selection. For Popper, revolutionary new theories constitute the main internal sources of variation in scientific theories. This happens when errors (obscurities) are identified in the dominant theory, when "we are disappointed in our expectations, or when our theories involve us in difficulties, in contradictions; and these may arise either within a theory, or between two different theories, or as the result of a clash between our theories and our observations" (Miller 1985, 179).

These variations (mutations) are transmitted by instruction. In the case of scientific theories, this occurs through social tradition or imitation and replication within scientific practice. Selection only occurs when new challenges or theoretical problems (environmental changes) force the emergence of new experiments, that is, tests to choose the theory best adapted to these environmental changes.

We are now in the stage of error elimination (less adapted theories). This happens through rationality: in the clash between competing theories, those that pass severe tests are corroborated, and those that do not must be eliminated to ensure progress. This, according to Popper, is a rational criterion, and there is little conventional or arbitrary element in this choice (Miller 1985). At this point, Popper opposes any attempt to preserve a theory through *ad hoc* hypotheses, for example. For the author, even if there is an intersubjective decision to continue investing in conclusively false theories, identifying their errors, their logical value as a scientific demarcation criterion does not lie in saving the theory.

Following this line, the author believes we cannot investigate what our best sources of knowledge are, but we can ask how to identify and eliminate errors. Popper says this is possible through criticism: "believe, by *criticizing* the theories or guesses of others and – if we can train ourselves to do so – by criticizing our own theories or guesses" (Popper 2002/1963, 34).

Criticism and training in identifying errors in theories are clearly related to the possibility of refuting theories, that is, only by attempting to falsify a theory can we find its errors and refute it, for according to Popper, "our falsifications thus indicate the points where we have touched reality" (Popper 2002/1963, 156).

Of course, errors for Popper refers to logic within a framework of severe testability. During severe testing, theories can be confronted with observations and proven false, indicating the existence of an error. If this occurs, they must be eliminated, as seen in the author's words: "to be eliminated if they clashed with observations; with observations which were rarely accidental but as a rule undertaken with the definite intention of testing a theory by obtaining, if possible, a decisive refutation" (Popper 2002/1963, 61).

The decision for refutation would be based on the identification of errors through empirical testing. Thus, for Popper, no theory can ever be certified as true in the logical-positivist sense of empirical verifiability, it's supposed capacity to coincide with sensory observation. What we can attain, rather, is certainty of a theory's falsity, for it is through the discovery of its errors that a theory reveals its limits.

Popper admits that for progress to occur, a struggle for survival is also necessary, in which the fittest triumph, solve our problems, and, having been well tested, withstand experimentation (not only because the fittest triumph were not refuted, but also because through critical evaluation they appear better than their competitors).

Selection here, unlike natural selection in the evolutionary theory of species, is not random and blind, but revolutionary (emerging theories with greater empirical content and refutability) and creative, arising from the competition between theories or the desire to

approach truth. Even so, Popper admits that his method cannot "guarantee" the survival of the fittest. Selection can go wrong: the fittest may perish, and the monsters may survive. After all, greater problems arise with each advance, but still science persistently and consciously seeks to eliminate errors.

Thus, according to Popper, in the struggle for survival among competing theories, the selection of the most adequate ones unfolds according to a set of epistemically grounded criteria. *Simplicity:* Theoretical progress requires a conceptual unification grounded in what Popper calls "some simple, *new, and powerful, unifying idea* about some connection or relation (such as gravitational attraction)" (Popper 2002/1963, 326). Simplicity, here, is not merely aesthetic; it marks a deeper structural economy through which a theory reveals previously unseen rational order.

Independent testability: A genuinely progressive theory must not only account for what its predecessor explained; it must also transcend it by generating novel and risky predictions. As Popper insists, it "must have new and testable consequences; it must lead to the prediction of phenomena" (Popper 2002/1963, 327) not yet observed. Only through such epistemic boldness can a theory avoid degenerating into *ad hoc* adjustments and preserve its claim to scientific fruitfulness.

Empirical success: The critical confrontation of theories with experience, articulated through *modus tollens*, is what constitutes the real engine of scientific growth. Empirical tests expose theoretical fragilities and, simultaneously, open pathways for conceptual renewal. Thus, Popper argues, "We must, that is, manage reasonably often to produce theories that entail new predictions, especially predictions of new effects, new testable consequences, suggested by the new theory and never thought of before" (Popper 2002/1963, 329).

Under these conditions, scientific knowledge advances not by the accumulation of certainties but by the systematic elimination of error, revealing in each theoretical failure the possibility of a more profound understanding of reality. The last criterion mentioned above, Popper says, may lead to the refutation of a theory that has met the previous criteria. But once its errors are found, it must be eliminated which, according to the author, is not negative, since the refutation of a theory is learning, and we should be grateful for the theory providing new experimental facts and now allowing us to know other problems. Through *modus tollens*, Popper observes, we falsify every theory.

Moreover, every decision, refutation, or maintenance of a conjecture in a theory occurs intersubjectively, even if rationally based on objective criteria.[10]

As we have seen above, the Popperian view of error differs from traditionalist views, mainly due to its understanding of error as a human, positive, and necessary aspect of scientific progress. However, regarding his response, some essential points of discussion about the problem of error in science can be raised. By admitting that we cannot arrive at approximate truth by eliminating errors, Popper assumes that:

[1] We are certain that we have identified the error. This Popperian assumption raises the following question: if truth cannot, in principle, be confirmed, how can errors be confirmed?
[2] That we must eliminate them, even if this does not occur in scientific practice.

[10] This conventionalist aspect of the Popperian view was criticized by the author Deborah Mayo (1996), who questioned the fact that Popper considered theory acceptance to be driven more by convention than by experimental evidence in his work. Mayo proposes a statistical view of inductive inference.

Errors and Progress in Feyerabend's Divergent Cosmological Pluralism

Feyerabend's response to the problem of errors in the progress of scientific knowledge is characterized by a progressive perspective that departs radically from the traditional view (Oliveira and Queiroz 2021). This perspective is directly tied to his pluralism. Scientific pluralism presents as a central argument the understanding that natural phenomena can be explained and investigated through multiple approaches; moreover, it clearly exposes the limitations of science and regards errors as fundamental to scientific inquiry, primarily because we are limited beings attempting to understand and engage with an external reality that appears highly complex, seemingly inexhaustible, and therefore unpredictable (Chang 2012).

Within this conception, Feyerabend's pluralism stands out in the philosophy of science precisely due to its emphasis on rejecting the limitations imposed by certain traditionalist conceptions, as it seeks to dissolve any notion of unity in science, including that of a single scientific method. Because of his criticisms in *Against Method* (1993) of the very idea of a scientific method, some authors interpret him as a methodological pluralist. However, Feyerabend goes beyond this, and his pluralism extends into the theoretical, epistemic, ontological, and cosmological domains. The latter dimension is further developed in his posthumously published book *The Conquest of Abundance* (1999), in which he aims to elucidate cosmology that is, an account of everything that exists at a fundamental level. Accordingly, Feyerabend argues that cosmological theories possess "a comprehensive view of the world, of society, of the situation of man which influences thought, behaviour, perception" (1993, 164).

As Oliveira notes, "Feyerabend assumed a form of divergent pluralism regarding the proliferation of cosmologies", drawing "inspiration from Darwin's Principle of Divergence" (Oliveira 2021, 429). Based on Oliveira's study, we incorporate into this debate the role of scientific errors in the progress of science.

For Feyerabend, errors are existentially tied to the confrontation between theories: a theory can only identify errors insofar as it is placed in contrast with another. His definition of error as "deviations from the accepted point of view" (Feyerabend 1981/1970, 38-39) therefore presupposes the existence of a dominant standpoint serving as a reference. As discussed in our section above titled "On the meaning of error: A distinction between deviation and mistake", this conception rests on the idea that error and deviation operate as synonyms, in the sense that both refer to the act of departing from an established course or a standard deemed legitimate.

In other words, error does not possess a universal or absolute character; it is always contextual and theoretically situated, emerging from disputes between theories (Oliveira and Queiroz 2021). This understanding establishes a first difference between the philosophies examined here: in the Popperian perspective, error is identified through logical criteria internal to the theory itself. In Feyerabend, by contrast, error becomes evident only through the external confrontation between cosmological alternatives.

This Feyerabendian conception is anchored in an analogy with the Darwinian struggle for survival, since, just as species compete for scarce resources in variable environments, scientific theories compete for material and human resources as well as for social prestige (Oliveira 2021). In this context, the dominant theory tends to prosper because it is better adapted to the "scientific environment" favorable to its development, whereas rival theories, often labeled "errors", remain marginalized.

Thus, errors also acquire a temporal dimension: evaluation criteria, scientific aims, and the very interests of inquiry change over time, thereby modifying what is considered an error. The parallel with Darwin even suggests that transformations in the "environment" may favor

theories previously rejected. Hence, in Feyerabend, there is no definitive determination of errors, a second feature that distinguishes him from Popper, since what is discarded at one historical moment may be rehabilitated later, as illustrated by debates between geocentric and heliocentric models.

Accordingly, we may say that, for Popper, the identification of errors is internal to the theory (logical contradiction or empirical testing). For Feyerabend, in contrast, error becomes visible only in the clash between rival cosmologies: it is a contextual variation, perceptible only through cosmological contrast. In other words, for Feyerabend, there is no definitive error.

Moreover, Feyerabend maintains that the most fruitful confrontation does not occur among closely related theories but among divergent cosmological theories, radically distinct worldviews capable of providing sharper external criticism. This seems more effective in exposing the errors of a rival theory, since a "contrast of a cosmological theories carries with it a sharper criticism about the ontological basis of that mainstream theory, and maybe of the general knowledge in itself" (Oliveira 2021, 430).

It is in this context that the introduction of divergent cosmological theories becomes fundamental. The rich proliferation of alternative theories, together with the tenacity of existing ones, creates the environment necessary for errors to become visible. Within this principle of proliferation, the analysis of error also deepens, since in many cases certain aspects of our knowledge can only be revealed by other theories, not by the facts, especially "hardly any theory is consistent with the facts. The demand to admit only those theories which are consistent with the available and accepted facts again leaves us without any theory" (Feyerabend 1993, 50).

By pointing out the errors of a dominant theory, we become able to explore new alternatives and, consequently, stimulate tests, criticisms, and changes in knowledge. In this context, Feyerabend distinguishes two types of errors: (i) *small errors*, which occur in restricted areas and can be corrected internally within a theory (Feyerabend 1978, 99); and (ii) *comprehensive or wide-ranging errors*.

Small errors generally occur "involving restricted areas", and where things "may perhaps be corrected from the inside" of the theory at hand (Feyerabend 1978, 99). That is, within the same "paradigm" the aim is the growth of the theory, and even when internal errors are identified, the effort is toward maintaining the theory. These errors are important to preserve a certain level of tenacity within the theory, for although science often replaces theories quite readily, there is also resistance within the scientific community to abandoning its main theoretical framework. Thus, scientists continue working even after such errors are identified and may either modify the theory or correct its flaws.

By contrast, *comprehensive or wide-ranging errors* involve "the 'basic ideology' of the field" (Feyerabend 1978, 99). At this point, the basic ideology, or paradigm, proves useless for detecting a broad range of errors, since it is too deeply entangled with all the elements of the cosmology.[11] Often, it is only with the help of alternatives that we are able to test, contrast, and uncover "the errors of highly respected and comprehensive points of view" (Feyerabend 1993, 132).

Thus, for the identification of errors we require "an external standard of criticism, we need a set of alternative assumptions or, as these assumptions will be quite general, constituting, as it were, an entire alternative world" (Feyerabend 1993, 22). In other words,

[11] This possibility of pointing out errors within the cosmological dimension of Feyerabendian pluralism can be expanded when it comes to incommensurable theories. According to Oliveira (2021), proliferation does not have to be incommensurable, although when it is, advancing our understanding.

the proliferation of divergent cosmological alternatives provides a fundamental basis for critically contrasting theories, especially those considered erroneous.

Based on Feyerabend's definition of error, as linked to divergent cosmological pluralism, we must ask what, after all, is the role of errors in scientific investigation. This function is already made explicit in Feyerabend's decisive claim "these 'deviations', these 'errors', are preconditions of progress" (Feyerabend 1993, 158)

From this perspective, knowledge is seen as a permanent process of learning from errors. On the one hand, we recognize that, given the complexity of nature, we will probably not reach a unified, perfect point of view capable of answering all remaining problems (Feyerabend 1993). On the other hand, this does not imply that errors are counterproductive; on the contrary, they are constitutive of the very dynamism of scientific progress. This is because a pluralist approach keeps science attentive to the fact that a theory may be upheld or may fail, and until we solve the problem, no one knows whether and to what extent our considerations about knowledge are imbued with errors.
In this sense, the pluralist approach, even if not at the cosmological level, recognizes the productivity of the presence of errors.

But cosmological pluralism provides a comparative worldview basis that deepens the discussion of errors, since comparison from outside the main theory offers sharper criticism in the debate between theories. As Feyerabend says, we require "an external standard of criticism, we need a set of alternative assumptions or, as these assumptions will be quite general, constituting, as it were, an entire alternative world" (Feyerabend 1993, 22).

From Feyerabend's understanding that errors are productive and necessary for the growth of knowledge, at least five philosophical functions of errors emerge, all articulated with divergent cosmological pluralism, in which the proliferation of alternatives and tenacity play central roles:

(a) Persistence Despite Errors

Often, errors identified in a theory do not lead to its immediate rejection. Scientists maintain their theories even while recognizing inconsistencies, whether due to a lack of better alternatives or because a small divergent minority has not yet convinced the dominant community.

Scientists frequently cling to their theories even while acknowledging such errors. They do not necessarily correct them immediately: sometimes theories are replaced, sometimes modified, and sometimes maintained simply because no better or more productive alternative exists. Moreover, even when the correction of an error is offered by a small divergent group of scientists, the scientific community as a whole is not always ready to accept it, particularly when this implies that its own view will be discredited. As recognized by Feyerabend when he states that a "contradiction may stay with us for decades or even centuries" (1993, 61).

Therefore, errors are preconditions for progress: they represent theories once considered absurd but that nonetheless provide elements for improvement; that is, identifying and correcting errors is not necessarily indispensable for progress to occur. Wray (2021) argues that false theories play an important role in Feyerabend's pluralism, as the author illustrates:

> I highlight a number of ways in which Brahe's theory changed the debate between early modern Ptolemaic astronomers, and the few early converts to the Copernican Theory. Even though Brahe's theory was not the theory ultimately accepted by the research community, its presence in the debate did enhance scientists' ability to evaluate the competing theories, as Feyerabend suggests. In addition, I draw attention to another important role played by false theories. I argue that Brahe's theory helped

> facilitate the change of theory, from Ptolemy's theory to Copernicus' theory. (Wray 2021, 73)

Wray's (2021) argument, by turning to this case from early modern astronomy, highlights a central point in Feyerabend's epistemology: false theories or errors are indispensable for scientific progress because, within the context of divergent cosmological proliferation, they provide contrast, enrich debate, and expand theoretical possibilities. Moreover, this function of errors reveals a sociological and historical aspect of the functioning of science: false theories may be maintained by the scientific community because they play important roles, such as preserving alternatives, stimulating critical debate, or, as in the case of Brahe's theory, facilitating a theoretical transition even if they are not true.

(b) Inevitability of Error

No theory is free of errors. Scientists know this and continue working to improve them even when such errors remain hidden. The history of science confirms that "logically perfect versions (if such versions exist) usually arrive only long after the imperfect versions have enriched science by their contributions" (Feyerabend 1993, 15).

Feyerabend emphasizes an epistemic and structural aspect of error in the dynamics of knowledge: errors are present in all theories and in all stages of scientific research. Even when they are not immediately detected, they do not impede theoretical development; on the contrary, they are part of the very process of refinement. In this context, the principle of tenacity ensures the survival of theories considered problematic, recommending their retention and further development.

Together with the principle of proliferation, tenacity ensures that theories that appear erroneous are not prematurely discarded. As Oliveira (2021) argues, progress is directly linked to divergent cosmological proliferation within Feyerabend's pluralism, supported precisely by these two principles: the introduction of cosmological alternatives and the consequent attempt to improve them, that is, tenacity promote scientific advancement.

Tenacity, defined as "the advice to select from a number of theories the one that promises to lead to the most fruitful results, and to stick to this one theory even if the actual difficulties it encounters are considerable" (Feyerabend 1981/1970, 137), provides space for so-called "error" theories to continue to develop. Eliminating them would mean eliminating potential paths of advancement.

An analogy with the synthetic theory of evolution helps clarify this dynamic: in evolutionary biology, mutations, though often harmful, are essential to guarantee genetic variability and enable adaptation to changing environments. Similarly, errors function as sources of epistemic variation. Erroneous theories constitute part of the set of alternatives available to science and are fundamental for preserving conceptual diversity. Just as mutations keep alive the possibility of adaptation, errors keep open investigative paths that may later prove fruitful.

Here we find a third divergence with the Popperian perspective. For Popper, progress consists in the systematic elimination of errors, and he explicitly criticizes the scientific community for sometimes retaining refuted theories or employing strategies to sustain inconsistent positions. For Feyerabend, however, this retention is precisely what makes progress possible: the proliferation of alternatives and their tenacious survival ensure that all remain in competition, as demonstrated by the history of science, in which "theories become clear and 'reasonable' only after incoherent parts of them have been used for a long time. Such unreasonable, nonsensical, unmethodical foreplay thus turns out to be an unavoidable precondition of clarity and of empirical success" (Feyerabend 1993, 17-18).

Thus, alternative theories may highlight aspects not explored by the dominant theory and reveal its errors and inconsistencies. This process of mutual criticism allows the

reassessment of errors and promotes theoretical improvement. The principle of tenacity therefore plays a crucial role by ensuring that initially problematic ideas are developed, confronted, and transformed rather than prematurely abandoned. From this perspective, there is no guarantee that tenacity applied to erroneous theories will lead to progress. Nonetheless, we should not restrict ourselves in advance, especially when divergent visions, criticisms, theories, and cosmological methods come from "outside the range of routine answers" (Feyerabend 1993, 169). Thus, structural and inevitable error is a condition of possibility for divergent cosmological pluralism.

(c) Errors as Historical Repertoire

Errors compose the historical repertoire of science. As Feyerabend writes, "there is no idea, however ancient and absurd, that is not capable of improving our knowledge. The whole history of thought is absorbed into science and is used for improving every single theory" (Feyerabend 1993, 33). Erroneous theories function as productive contrasts, revealing limitations of dominant views and reminding us of those alternative perspectives, grounded in different cosmologies, can illuminate neglected aspects of reality.

An expressive example is the ancient theory of spontaneous generation – the belief that living beings could arise directly from inanimate matter. Although errors, this conception motivated Redi's experiments, methodological debates in the seventeenth century, and later Pasteur's definitive tests, which consolidated modern microbiology. Thus, a refuted theory ended up playing an essential role in building experimental practices and refining biological concepts.

In this sense, the divergent cosmological pluralism defended by Feyerabend helps us understand the relevance of this process: by asserting that different worldviews, including those considered error, outdated, or "non-scientific", may contribute to the advancement of knowledge, Feyerabend maintains that science progresses precisely when it can confront its own assumptions with heterogeneous alternatives. The theory of spontaneous generation, by competing with emerging explanations of life and provoking critical investigations, exemplifies how the coexistence of divergent cosmologies creates cognitive tension, expands the field of problems, and enables discoveries that would not emerge in a methodologically homogeneous environment.

(d) Errors as Warnings

Errors also function as warnings, a record of what should not be repeated. The history of science contains emblematic examples, such as phrenology, which illustrate how conceptions now recognized as errors were deeply integrated into the social worldviews of their time. Even errors with negative impact retain epistemic and ethical value, as they reveal the historical conditions of scientific production and guide future transformations.

(e) Errors, Education, and Citizenship

In the context of divergent cosmological pluralism, errors play an additional function: they contribute to scientific education oriented toward the critical autonomy of citizens. If science advances through errors, revisions, and incompatible alternatives, hiding this dynamism not only distorts the actual nature of scientific practice but also undermines civic education.

Feyerabend rejects the idea that the public is incapable of dealing with the plurality of scientific opinions and their inevitable fallibility. On the contrary, an education that exposes this plurality is a necessary condition for exercising critical citizenship. What truly harms an adequate description of science and, consequently, its credibility, is the attempt to conceal

flaws, the specialist "acting as if it did not exist" (Feyerabend 1993, 251). Such a stance reveals a misunderstanding of how scientific knowledge is constituted and develops.

In this sense, errors have a formative role: by revealing the contingency, historicity, and contested nature of scientific knowledge, they provide basic tools for critical decision-making in society. This does not weaken public trust in science; on the contrary, it strengthens it, since it promotes a mature understanding that science advances precisely through its openness to error, revisions, and alternatives.

This perspective contrasts with the Popperian view. For Popper, the focus is on normative rigor, critical testing, and the systematic elimination of errors, a disciplined image of science. For Feyerabend, however, errors also have pedagogical, democratic, and emancipatory value: they are essential for forming citizens capable of critically understanding scientific practice and participating in informed decision-making in the public sphere.

In summary, Feyerabend's response to the problem of errors in scientific progress reveals a deeply pluralist conception, in which error is not an obstacle to be eliminated but a constitutive element of the very dynamics of knowledge. Feyerabend understands error as the product of confrontation between divergent cosmologies, indispensable for expanding alternatives, revealing hidden limitations, and preventing premature closure of inquiry. The proliferation of theories, tenacity, and the coexistence with false or marginalized conceptions make error inevitable, historically productive, and epistemically indispensable. Thus, far from representing a deviation to be corrected, error in Feyerabend illuminate's possibilities, enriches debates, and strengthens both scientific advancement and the critical formation of citizens capable of understanding the open, contested, and creative character of science.

Conclusion

The present investigation did not seek an exhaustive comparison between Popper and Feyerabend but aimed to make explicit how their progressive conceptions of error converge in the rejection of traditionalism and, at the same time, diverge decisively in their understanding of scientific progress. This divergence reveals not only methodological differences but, above all, deep epistemological tensions concerning the very mode of existence of scientific error.

The Popperian perspective represents an advance in relation to traditionalist views by abandoning the pretension of preventing errors and transforming them into methodological instruments. However, Popper preserves a robust normative rationalism: errors must be identified and eliminated as early as possible, for scientific progress is essentially substitutive. Falsified theories must be discarded, and more audacious theories with greater empirical content must take their place.

Feyerabend breaks more radically with this framework. For him, errors not only accompany scientific progress but constitute it. Equivocal, inconsistent, or already refuted theories must be preserved through tenacity and the proliferation of alternatives, for they provide critical contrasts capable of revealing the limitations of dominant theories. Error, therefore, is not something to be quickly eliminated, but an epistemic resource fundamental for expanding problematic horizons, generating cognitive tension, and allowing different cosmologies to illuminate neglected aspects of reality. Thus, what Popper considers a vice- the resistance of scientists to abandon their theories- becomes, in Feyerabend, an epistemological virtue.

This difference also manifests itself in how each philosopher conceives the detection of error. In Popper, identification is internal, resulting from logical contradictions or direct confrontation with the facts. In Feyerabend, by contrast, identification is external: only the

contrast between divergent cosmologies makes the limitations of any isolated perspective visible.

More profoundly, Popper continues to offer a normative methodology about how science should proceed, whereas Feyerabend realistically describes how science operates (historically, institutionally, sociologically). For this reason, the Feyerabendian approach is epistemically more progressive: by abandoning the search for fixed criteria and replacing methodological purity with the historical proliferation of rival cosmologies, his analysis incorporates the real complexity of scientific practice.

Finally, both perspectives have important implications for scientific education and citizenship, though in different senses. Popper provides a disciplined, regulative image useful for understanding the importance of critical testing. Feyerabend, however, shows that coexistence with errors, alternatives, and conflicts is a condition for forming mature citizens capable of participating in decisions involving science and society. Instead of protecting the public from scientific fallibility, he argues that exposure to plurality is an essential part of a democratic culture.

It follows, therefore, that investigating the notion of error from the perspective of Feyerabend enriches, in a more profound way, our understanding of the fallible, experimental, and plural nature of science. While Popper offers a regulative model centered on the rational elimination of errors, Feyerabend reveals the heuristic, historical, and emancipatory potential of these same errors. The tension between these conceptions not only deepens the epistemological debate but also offers distinct pathways for thinking about scientific progress and the formation of a critical scientific culture.

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