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Post-Normal Modelling and the Epistemology of Ignorance *

Modelización posnormal y epistemología de la ignorancia

Modelização pós-normal e epistemologia da ignorância

Alberto Fragio Gistau and Óscar Carpintero **

In this article, we examine the role of the epistemology of ignorance in Post-Normal Science (PNS) modelling. First, we distinguish between conventional and post-normal models in terms of their treatment of idealization, knowledge, and ignorance. We then review major contributions to the epistemology of ignorance within the PNS tradition, focusing on the work of Jerome Ravetz, Steve Rayner, George Lakoff, Silvio Funtowicz, and Mario Giampietro. Next, we compare these perspectives with the views of Funtowicz, Giampietro, Andrea Saltelli, and Kozo Mayumi, drawing on a questionnaire that explores the emergence of a new PNS modelling style, the role of ignorance, the challenge of relativism in model building, and critiques of Integrated Assessment Models (IAMs). Finally, we address common criticisms of PNS and conclude that the epistemology of ignorance provides valuable analytical tools for the de-idealization of scientific models. It should therefore be recognized as a central component of PNS modelling, as it helps maintain critical openness to alternative framings while preventing distortions and oversimplifications.

Keywords: *post-normal science; modelling; de-idealization; ignorance; framing; hypocognition*

En este artículo examinamos la función desempeñada por la epistemología de la ignorancia en la modelización posnormal. En primer lugar, distinguimos entre modelos convencionales y posnormales en relación con su tratamiento de la idealización, el conocimiento y la ignorancia. A continuación, revisamos las principales contribuciones a la epistemología de la ignorancia dentro de la tradición de la ciencia posnormal, centrándonos en los trabajos de Jerome Ravetz, Steve Rayner, George Lakoff, Silvio

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** *Alberto Fragio Gistau:* professor in the Department of Philosophy at the University of Oviedo, Faculty of Humanities, Spain. Email: fragioalberto@uniovi.es. ORCID: https://orcid.org/0000-0003-3229-5977. *Óscar Carpintero:* full professor in the Department of Applied Economics at the University of Valladolid, Faculty of Economics and Business, Spain. Email: carpin@uva.es. ORCID: https://orcid.org/0000-0001-9142-8931.

Funtowicz y Mario Giampietro. Asimismo, contrastamos estas perspectivas con las opiniones de Funtowicz, Giampietro, Andrea Saltelli y Kozo Mayumi mediante un cuestionario cualitativo sobre la emergencia de un nuevo estilo de modelización posnormal, la ignorancia, el desafío del relativismo en la construcción de modelos y las críticas a los modelos de evaluación integrada. Finalmente, abordamos algunas críticas comunes a la ciencia posnormal y concluimos que la epistemología de la ignorancia proporciona herramientas analíticas valiosas para la desidealización de los modelos científicos. Por ello, debería ser reconocida como un componente central de la modelización posnormal, ya que favorece una apertura crítica hacia marcos alternativos de interpretación, al tiempo que contribuye a evitar distorsiones y simplificaciones excesivas.

Palabras clave: ciencia posnormal; modelización; desidealización; ignorancia; marcos cognitivos; hipocognición

Neste artigo, examinamos o papel desempenhado pela epistemologia da ignorância na modelização pós-normal. Em primeiro lugar, distinguimos os modelos convencionais dos pós-normais em termos do seu tratamento da idealização, do conhecimento e da ignorância. Em seguida, revisamos as principais contribuições para a epistemologia da ignorância no âmbito da tradição da ciência pós-normal, com foco nos trabalhos de Jerome Ravetz, Steve Rayner, George Lakoff, Silvio Funtowicz e Mario Giampietro. Posteriormente, comparamos essas perspectivas com as posições de Funtowicz, Giampietro, Andrea Saltelli e Kozo Mayumi, com base num questionário qualitativo que explora o surgimento de um novo estilo de modelização pós-normal, o papel da ignorância, o desafio do relativismo na construção de modelos e as críticas aos modelos integrados de avaliação. Por fim, abordamos algumas críticas recorrentes à ciência pós-normal e concluímos que a epistemologia da ignorância fornece ferramentas analíticas valiosas para a desidealização dos modelos científicos. Por conseguinte, ela deve ser reconhecida como um componente central da modelização pós-normal, uma vez que favorece uma abertura crítica a quadros alternativos de interpretação, ao mesmo tempo que contribui para evitar distorções e simplificações excessivas.

Palavras-chave: ciência pós-normal; modelização; desidealização; ignorância; enquadramentos cognitivos; hipocognição

Introduction

Post-normal science (PNS) emerged to address the challenge of providing reliable scientific advice under conditions characterized by uncertainty, contested values, high stakes, and urgent decision-making. In domains such as environmental sustainability, technological risk management, public health, and climate change, conventional scientific methods often fall short, as they may be unable to deliver definitive certainties or purely technical solutions. In this context, extended peer communities are regarded as a key mechanism for ensuring the quality of scientific advice. PNS advocates the inclusion of all stakeholders with a direct or indirect interest in the problem, including citizens, social organizations, workers, users, and local authorities. This broader participation not only acknowledges the diversity of experiences and forms of knowledge but also enables the integration of values, concerns, and perceptions that are inevitably involved in addressing complex problems. The presence of irreducible uncertainties, ethical disagreements, and limited control over potential outcomes further underscores the need to recognize multiple legitimate perspectives. In this way, PNS reframes the role of scientific knowledge: it is not merely about producing objective truths but about supporting informed and socially responsive decision-making. By embracing complexity, transdisciplinarity, and participatory approaches, it offers a framework for science that is both epistemologically robust and socially relevant.

Since the pioneering contributions of Funtowicz and Ravetz, the PNS approach has been further developed and extended to areas such as citizen science (Irwin, 1995), sustainability transitions (Loorbach, 2014; Loorbach & Rotmans, 2010), degrowth (D'Alisa, Demaria, & Kallis, 2014), and epidemiology (Waltner-Toews *et al*., 2020), among other fields (Funtowicz & Ravetz, 2025; Kovacic & Biggeri, 2023). Moreover, the challenges of providing scientific advice for policymaking have prompted a distinctive epistemological reflection on scientific modelling (Saltelli & Funtowicz, 2014; Saltelli *et al*., 2020).

In a previous article (Fragio & Carpintero, 2024), we addressed the specific topic of PNS modelling. We focused on several leading Post-normal scholars, including Silvio Funtowicz, Mario Giampietro, Andrea Saltelli and Kozo Mayumi, who respond here to a questionnaire. In our view, PNS modelling has not only contributed to the general epistemology of models, but has also introduced several strategies to improve the quality of modelling in sustainability science and ecological economics. We presented criticism directed in particular at conventional ecological-economic modelling. In this context, "Quantitative Storytelling" (QST) (Giampietro & Bukkens, 2022; Saltelli & Giampietro, 2017) was considered a step forward in the epistemology of PNS modelling, as a tool to overcome common blunders in the use of conventional models to inform policy in the field of sustainability science.

In this article, we focus on an important area of development within PNS modelling, namely the epistemology of ignorance. We argue that the epistemology of ignorance is a central feature of PNS modelling and should be regarded as a key factor in the de-idealization of scientific models. Section 1 outlines the distinction between conventional models and post-normal models with regard to the role of idealization, knowledge and

ignorance. In section 2, we focus on contributions to the epistemology of ignorance that have attracted attention among post-normal scholars. In particular, we review the work of Jerome Ravetz, Steve Rayner, George Lakoff, Silvio Funtowicz and Mario Giampietro on this topic. In section 3, we compare the results of our survey on epistemology of ignorance and PNS modelling with the views of Funtowicz, Giampietro, Saltelli, and Mayumi. They responded to a questionnaire on the emergence of a new PNS modelling style, the epistemology of ignorance, the challenge of relativism in model building, and criticism of Integrated Assessment Models (IAM). In section 4, we address common criticisms of PNS and conclude that epistemology of ignorance offers a set of analytical tools for the de-idealization of scientific models and should be considered a prominent feature of PNS modelling.

1. Normal and post-normal models

Scientific models are generally understood as stylized representations of a phenomenon, typically called a target system (Frigg, 2022; Frigg & Hartmann, 2025). Illustrative examples include Bohr's atomic model, the double-helix model of DNA, and the Phillips-Newlyn hydraulic model of a macroeconomy. Models involve idealization, i.e., the deliberate simplification of the target system in order to enhance understanding. Common cases of idealization include point masses, ideal gases, rational agents, and simplified populations. Idealization is often distinguished into Aristotelian idealization, which omits certain properties of the target system, and Galilean idealization, which deliberately distorts or deforms features to make the system analytically or computationally tractable. In practice, both types frequently coexist: models typically both exclude and distort aspects of reality, sometimes resulting in caricature or toy models (Batterman & Rice, 2014; Frigg & Hartmann, 2025; Gibbard & Varian, 1978). Related notions, such as minimal models, refer to highly simplified representations that retain only key causal factors (Weisberg, 2007, p. 642-643). Idealization is also often understood as a preliminary step, with the expectation that models can later be de-idealized to improve accuracy and representational adequacy.

Building on the pioneering work of Silvio Funtowicz and Jerome Ravetz, a distinctive approach to scientific modelling has emerged that has proven especially influential in the development of ecological-economic models (Fragio & Carpintero, 2024). As already mentioned, at the core of PNS lies the problem of scientific advice in policy-making —what Funtowicz and Ravetz (1990) famously described as "science for policy," namely, the challenges that arise when scientific knowledge is mobilized to inform public decisions (Funtowicz & Ravetz, 1993, p. 740). PNS originated from the practical need to ensure the quality and reliability of scientific advice under conditions in which conventional scientific procedures are insufficient. Such "post-normal conditions" arise when facts are uncertain, values are contested, stakes are high, and decisions are urgent. Under these circumstances, policies informed by scientific expertise may generate profound and far-reaching consequences, often accompanied by significant unintended effects. Typical examples include the civilian and military uses of nuclear energy, the widespread application of synthetic pesticides, and the challenge of managing pandemics.

The problem of science for policy has stimulated a distinctive epistemological debate concerning the nature and role of scientific models (Saltelli & Funtowicz, 2014; Saltelli *et al*., 2020). When science operates under post-normal conditions, modelling cannot rely on reductionist assumptions. Practical problems can no longer be decomposed into isolated technical questions; instead, a complexity-based approach must be adopted. This gives rise to the need for a new style of modelling, namely, PNS modelling, characterized by a high degree of uncertainty, and in some cases even by sheer ignorance (Fragio & Carpintero, 2024; Funtowicz & Strand, 2007, pp. 263-278). The difference between conventional modelling and PNS modelling lies not only in the fact that the former is usually confined to a specific disciplinary domain, while the latter is geared toward addressing pressing practical problems with broad social implications, but also in their epistemological focus: conventional modelling emphasizes what is known, or thought to be known, whereas PNS modelling places emphasis on what is unknown, uncertain, or fundamentally unknowable. When uncertainty cannot be eliminated from modelling, the quality of scientific information and policy advice depends precisely on how well that uncertainty is managed (Funtowicz & Ravetz, 1993, pp. 735-755).

This does not imply that conventional modelling is inherently flawed. Rather, it suggests that, under post-normal conditions, modelling practices must be adapted to the epistemological assumptions of PNS. These assumptions involve reconsidering a series of traditional dichotomies, including those separating facts from values, knowledge from ignorance, and experts from lay citizens (Funtowicz & Ravetz, 1993). The guiding principle of this alternative modelling paradigm is captured in the well-known slogan “quality rather than truth” (Funtowicz & Ravetz, 1994b, pp. 204-205). This formulation signals a shift away from the pursuit of certainty toward an emphasis on the robustness, relevance, and transparency of the information underpinning scientific advice. Yet PNS modelling remains grounded in a normative vision of how models should be developed, emphasizing the importance of critically engaging with alternative framings and creating space for disagreement, so that perspectives that might otherwise be marginalized or excluded are brought into the discussion. Models should explicitly identify their assumptions, avoid unnecessary complexity, acknowledge uncertainties, resist misuse for rhetorical or political purposes, and remain transparent and replicable, allowing scrutiny by other researchers and stakeholders to ensure both reliability and credibility (Fragio & Carpintero, 2024; Saltelli *et al*., 2020).

In this regard, our main argument is that PNS modelling should be guided by a strategy of de-idealizing models through the critical examination of ignorance, a feature that is central to the post-normal approach. This argument builds on theoretical contributions developed by scholars within the PNS tradition, which provide the foundations for conceptualizing model de-idealization in terms of an epistemology of ignorance. From this perspective, PNS modelling can be understood as being driven by a critique of ignorance that enables the de-idealisation of scientific models. In what follows, we substantiate this claim by examining the respective roles of uncertainty and ignorance within PNS.

2. Post-normal science and epistemology of ignorance

PNS originally incorporated an epistemology of uncertainty for ensuring quality science and scientific advice (Funtowicz & Ravetz, 1990; Walker *et al*., 2003). In this context, uncertainty is not only understood as a lack of data or the variability of results, but is defined by the complex interplay between uncertain facts, conflicting values, and urgent decisions. It is not just a matter of knowing that something is uncertain, but of understanding how that uncertainty affects decisions and the way knowledge is valued. That is why Funtowicz and Ravetz (1990) created NUSAP, a notation system for managing and communicating uncertainty in scientific information, which was subsequently refined and extended by van der Sluijs through his long-standing collaboration with the Netherlands Environmental Agency (van der Sluijs *et al*., 2005; van der Sluijs, 2017).

Closely related to this tradition is the practice of sensitivity auditing. It involves a critical scrutiny of the assumptions, values, and framing of the model itself (Saltelli & Funtowicz, 2014; Vannucci *et al*., 2025). In this sense, sensitivity auditing may be considered an extension of sensitivity analysis, which tests the robustness of conclusions by varying input parameters and observing variations in outputs to determine how sensitive the model is to different scenarios. Sensitivity auditing for assessing uncertainty has been included in authoritative sources such as the Science Advice for Policy by European Academies (SAPEA) report (2019) and the European Commission's Better Regulation Toolbox (European Commission, 2023).

Building on these foundations, we consider the epistemology of ignorance to be a step beyond the epistemology of uncertainty. However, it should be noted that the difference between uncertainty and ignorance still remains a highly debatable topic (Birkenholtz & Simon, 2022). Based on Frank Knight's famous work (1921), uncertainty is usually understood as a situation where there may be confidence in the range of possible outcomes, but the available information does not provide a definitive basis for deriving probabilities. In contrast, ignorance implies that neither probabilities nor outcomes can be fully characterised (Dovers & Handmer, 1995; Stirling 2010; Stirling *et al*., 1999). That is to say, in a state of ignorance we do not know what we do not know (Scoones & Stirling, 2020; Stirling, 2017, p. 272). Rather than focusing on uncertainty within PNS, this paper highlights how recent insights into ignorance are opening up new directions for what we call PNS modelling.

On the other hand, the scholarly literature on ignorance has grown significantly in recent years (Fernández, 2019 & 2015; Gross & McGoey, 2015; Oreskes, 2024; Verburgt, 2024; Verburgt & Burke, 2021; Wehling, 2021). In particular, the history of knowledge and ignorance has been explored by various authors who have contributed to the development of the field. For instance, Peter Burke (2015) delves into the evolution of knowledge throughout cultural history. Similarly, Alain Corbin (2021) focuses on the history of ignorance. Other important contributions to ignorance studies include Shannon Sullivan and Nancy Tuana (2007), who examine the social implications of ignorance, and Robert N. Proctor and Londa Schiebinger (2008), who developed agnotology, namely, the study of the making and unmaking of ignorance. With regard

to scientific ignorance, different approaches analyze the intertwining of scientific knowledge and ignorance. The protosociology of science, for example, examines how scientific thinking directs attention to certain objects while ignoring others, a bias studied by Ludwik Fleck (1979). The sociology of scientific knowledge, in turn, stresses the importance of social and cultural factors in the construction of ignorance, as in the approach developed by David Bloor (1976). Another relevant aspect is the concept of "undone science", proposed by Scott Frickel *et al*. (2010), which looks at the intersection of social studies of science and social movement studies. Finally, the cultures of non-knowledge approach examines how knowledge and ignorance are co-produced within scientific cultures (Wehling, 2015; Wehling & Böschen, 2015).

Within this broad tradition of scholarship on scientific ignorance, we will focus only on the contributions of Ravetz, Rayner, Lakoff, Funtowicz, and Giampietro, since they have attracted the greatest attention among ecological-economic modellers, particularly among those influenced by PNS (**Table 1**).

Table 1. Epistemology of ignorance

Concept	Summary	References
Usable Ignorance	To place ignorance at the service of improving policy interventions inspired by scientific knowledge.	Ravetz (1986)
Social Construction of Ignorance	A social or institutional preference that leads to the ignoring of certain facts.	Ravetz (1986), Rayner (1986)
Uncomfortable Knowledge	Disruptive knowledge (i.e., "unknown knowns") is kept at bay because of its potential to expose latent dissent and the precariousness of an existing agreement.	Rayner (2012)
Hypocognition	When the cognitive frames required to fully understand a given problem are not available.	Lakoff (2004, 2010)
Hegemonic Storytelling	The predominance of a particular narrative that overshadows other legitimate and meaningful perspectives.	Funtowicz and Ravetz (1994a, 1994b), Giampietro (2018b, 2019, 2024)

Source: own elaboration.

2.1. Usable ignorance and social construction of ignorance

In his famous 1986 contribution, Jerome Ravetz addresses the close link between ignorance and scientific knowledge when it comes to environmental issues (Wehling,

2021). He suggests defining "usable knowledge" as that type of scientific knowledge applied to policy-making for the solution of a specific technical issue. However, environmental sciences —or "biosphere sciences", as he calls them— typically produce "scientific ignorance". On this basis, he advocates an amendment to the traditional understanding of science as a progressive enterprise of unlimited accumulation of knowledge, and suggests the importance of moving towards "usable ignorance", which would serve the purposes of self-criticism and control applied to science and the policies it informs. Oftentimes, environmental problems involve "low prestige and immature fields, requiring data bases that simply do not exist, being required to produce answers in a hurry, they are not the sort of inquiry where success of any sort can be reasonably expected" (Ravetz, 1986, p. 422). Accordingly, scientists should not only acknowledge their momentary ignorance, but also recognise that it is possible that they will never get past it, at least not in time to make the right decision.

From the point of view of environmental concerns, such as acid rain or the treatment of nuclear waste, the traditional view of science as an epistemologically progressive enterprise is unsuitable for the new task of environmental risk governance. Even worse, the old ideal of an authoritative science which is certain of its recommendations turns into a mechanism of "the social construction of ignorance". Science itself, Ravetz argues, has encountered unsolvable problems, and while knowledge increases exponentially, our ignorance increases even more rapidly, particularly when ignorance has been generated by science itself, that is, scientific ignorance. Within this framework, usable ignorance comes to the fore, for example, in the monitoring of environmental risks, where a kind of permeable border is designed to detect the first signs of incipient unknown processes. When it comes to environmental assessment, ignorance can become severe, and whenever it is recognized as such, "then no amount of sophisticated calculation with uncertainties in a decision algorithm can be adequate for a decision. Nonquantifiable, perhaps nonspecifiable, considerations of prudence must be included in any argument" (Ravetz, 1986, p. 429), to ensure that the precautionary principle is applied both theoretically and practically (Tickner & Riechmann, 2002). Therefore, it is necessary, in his opinion, to invent "a new scientific style to respond to the new scientific problems of the biosphere, simultaneously with the special researches that are at its basis" (Ravetz, 1986, p. 430). This new scientific style should be based on the awareness of our own ignorance, because only then will we avoid incurring disastrous errors arising from imperfect knowledge or supposedly effective technique.[1]

In his commentary on Ravetz's text, Steve Rayner (1986) lingers on the social construction of ignorance, and clearly anticipates what would later be termed "agnotology" (Proctor & Schiebinger, 2008), that is, when deliberately or unconsciously it is chosen not to know; when a social preference dictates the ignoring of certain facts. While Ravetz's purpose is to place ignorance at the service of improving intervention

[1] It is worth mentioning that Ravetz also coined the expression "science-based ignorance" and referred to "man-made ignorance", namely, when anthropic activities alter natural cycles and systems in an unknown and dangerous way. For further developments, see Ravetz (2015a, 2015b) and Wehling (2021).

policies inspired by scientific knowledge, Rayner goes one step further and argues that we need to recognize a "structural amnesia in science". He also points out that "explicit recognition that some kinds of ignorance are socially constructed may facilitate the construction of truly interdisciplinary approaches to science for policy" (Rayner, 1986, p. 434).

2.2. Uncomfortable knowledge

Steve Rayner (2012) takes up the issue of the social construction of ignorance. He argues that this process entails the systematic omission of "uncomfortable knowledge". In his opinion, "sense-making is possible only through processes of exclusion. Storytelling is possible only because of the mass of detail that we leave out" (Rayner, 2012, p. 111). In order to develop coherent understandings of the world and act within it, both individuals and institutions need to reduce its complexity: "The process of doing so means that much of what is known about the world needs to be excluded from those versions, and in particular that knowledge which is in tension or outright contradiction with those versions must be expunged. This is 'uncomfortable knowledge'" (Rayner, 2012, p. 107). To illustrate this argument, Rayner refers to Donald Rumsfeld's famous and highly satirized statement, in which the former U.S. Secretary of Defense distinguishes among "known knowns" (what we know we know), "known unknowns" (what we know we don't know), and "unknown unknowns" (what we don't know we don't know) (Donald Rumsfeld, cited in Rayner, 2012, pp. 107-108; Ravetz, 2015b). To this taxonomy, Rayner adds "what is possibly the most intriguing combination": "what we don't know we know" or "unknown knowns".

In this interplay between knowledge and ignorance, Rayner identifies "uncomfortable knowledge" as "unknown knowns". According to him, institutions actively exclude uncomfortable knowledge either because it challenges their purposes or because it threatens their stability. As he explains, "my interest is therefore in how information is kept out rather than kept in and my approach is to treat ignorance as a necessary social achievement rather than as a simple background failure to acquire, store and retrieve knowledge" (Rayner, 2012, p. 108). He also refers to this mechanism as "institutionalized forgetfulness".

Ultimately, uncomfortable knowledge can be seen as a manifestation of a persistent problem that remains inadequately resolved. We thus arrive at what might be termed, for mnemonic purposes, the "Rayner equation": "wicked problems" + "clumsy solutions" = "uncomfortable knowledge" ($P_w+S_c=K_u$). In this formulation, uncomfortable knowledge emerges as the by-product of attempts to address wicked problems through inherently imperfect or "clumsy" institutional arrangements.

Wicked problems are characterized by their complexity and resistance to definitive solutions. Their very definition often varies depending on the range of solutions under consideration, and they may ultimately prove unsolvable. Moreover, their causal mechanisms are frequently difficult to identify, and they often appear as symptoms of

broader or interconnected problems.[2] Rayner cites climate change and water resource management as examples of wicked problems.

Clumsy solutions are characterized by a superficial or artificial convergence among stakeholders. Rather than resting on robust ethical and epistemological foundations, they rely on forms of consensus that accommodate competing interests without adequately addressing their underlying assumptions. As inherently pluralistic arrangements, clumsy solutions do not seek to optimize outcomes; instead, they aim to secure a level of satisfaction among the parties involved while leaving their ultimate motivations largely unquestioned. Rayner cites the implicit consensus surrounding U.S. nuclear energy policy in the 1980s as a paradigmatic example of a clumsy solution.

"Uncomfortable knowledge" can thus be understood as a form of disruptive knowledge held by one or more of the actors involved, with the potential to expose the latent disagreements and fragility underlying a given arrangement. It is, in other words, knowledge capable of revealing both the divergence among competing interpretations and the weakness of institutional arrangements. In this context, Rayner identifies four implicit strategies —arranged in increasing order of sophistication— through which institutions seek to keep uncomfortable knowledge at bay: 1) denial ("there is no problem"); 2) dismissal ("it is only a minor problem"); 3) diversion/decoy ("we are working on it"); and 4) displacement ("the model we are developing will solve the problem").[3]

In short, Rayner recommends implementing compensatory strategies that prevent the systematic exclusion of uncomfortable knowledge in the representation of insidious problems, since key information for addressing them more effectively may be contained within "unknown knowns".

2.3. Framing, hypocognition, and hegemonic storytelling

The last contribution to the epistemology of ignorance applied to environmental issues that we would like to consider is a brief article by George Lakoff entitled "Why It Matters How We Frame the Environment" (2010), in which the American linguist introduces the concepts of "framing" and "hypocognition". Building on his earlier work, *Don't Think of an Elephant: Know Your Values and Frame the Debate* (2004), Lakoff argues that facts only acquire meaning when they are embedded within a "frame" system; otherwise they remain cognitively inaccessible or unrecognized. At the same time, effective communication of facts requires the activation of appropriate cognitive frames (Lakoff,

[2] García and You (2016) point out that insidious problems cannot be adequately modeled, since "detailed process systems models for it do not yet exist at a level satisfactory for important decisions" (cited in Giampietro, 2018a, p. 8).

[3] It should be noted that Rayner presents a case of ecosystem modelling as an example of "displacement". In particular, he refers to a eutrophication problem in the Chesapeake Bay, attributed to industrial activity, agricultural runoff, and coastal urban expansion.

2010, p. 73).[4] Thus, for example, in order to understand a complex phenomenon such as global warming, individuals must possess a sufficiently sophisticated network of frames, without which the full scope and meaning of the problem cannot be adequately grasped. The process of constructing the cognitive frameworks that enable the comprehension of a given fact is what Lakoff calls "framing". As he explains, "words themselves are not frames. But under the right conditions, words can be chosen to activate desired frames. This is what effective communicators do. In order to communicate a complex fact or a complex truth, one must choose one's words carefully to activate the right frames so that the truth can be understood. If the hearer has no such frames, then you have to choose your words carefully to build up those frames" (Lakoff, 2010, p. 73).

When the frames required to fully understand a given problem are not available, "hypocognition" occurs. Lakoff has described this as the "tragedy of the absence of frames", a phenomenon he identifies as particularly prevalent in politics, but also in economics and environmental issues. As he notes, "we are suffering from massive hypocognition in the case of the environment" (Lakoff, 2010, p. 76). The absence of the key frames needed to understand ecological problems has thus been termed "environmental hypocognition". As Lakoff explains, the environment is not confined to environmental issues alone, but is closely interconnected with domains such as economics, energy, food, health, trade, and security. Within these overlapping areas, citizens, leaders, policymakers, and journalists often lack the frames necessary to capture the complexity of the situation. Consequently, he argues that any form of activism should recognize the need to construct and disseminate such frames within the public sphere. These insights also point to the value of cross-disciplinary approaches for improving frame analysis beyond the limits of any single discipline.

Complementary to the notions of "framing" and "hypocognition", Mario Giampietro (2019) introduces the concept of "hegemonization of storytelling" to describe the predominance of a given system of frames, particularly widely disseminated normative narratives. Building on earlier work by Funtowicz and Ravetz (1993, 1994a), Giampietro associates this hegemonization with the "'*ancient régime*' syndrome", whereby communities become "frozen" in their prevailing convictions. As he explains, "an excessive hegemonization of storytelling in a society can generate a situation of 'ancient régime' syndrome defined as 'a state of affairs in which the ruling elites become unable to cope with stressors and adopt instead a strategy of denial, refusing to process either internal or external signals, including those of danger'" (Giampietro, 2019, p. 17; after Funtowicz and Ravetz, 1994a, p. 576; Nickerson, 1998). This dynamic can be observed, for instance, in hegemonic narratives surrounding industrial agriculture and sustainability discourse (Giampietro, 2018b, 2019, 2024).

In this line of thought, it is also worth noting that Giampietro, Allen, and Mayumi have emphasized the relevance of ignorance and hegemonization in the framing of models (Giampietro, Allen & Mayumi, 2006). When modelling complex adaptive systems, the

[4] For a discussion of framing and communication, see Fragio (2022, chap. 2).

observer's perspective must be incorporated in some way into the modelling itself, insofar as it shapes the choice of the scale at which observations are conducted. Thus, for example, within a food system, an agronomist may focus on yields per hectare and input-use efficiency, whereas a socio-metabolic approach would instead examine flows of energy, labor time, and the requirements of social reproduction.

Mayumi and Giampietro (2006) argue that complex phenomena involve multiple levels and scales of observation, which in turn entails recognition of non-equivalent descriptive domains and non-reducible models. This challenges reductionist approaches that assume reality can be modelled in a unitary fashion through the integration of distinct scales and domains. On the contrary, they maintain that a simultaneous, fully integrated, and comprehensive representation of all interactions within a complex system is not feasible. This raises the problem of relativism in model building: by privileging specific variables, scales, and causal relations, every model necessarily excludes other dimensions of reality that may be equally relevant for understanding system behavior, depending on the observer's interests and perspective. In this sense, ignorance is not merely a lack of information, but also an inherent outcome of model framing. Furthermore, hegemonic narratives may arise when a particular descriptive domain is presented as the only legitimate foundation for decision-making, thereby obscuring alternative interpretations of the system as well as the forms of ignorance embedded in the model itself. Consequently, one of the central epistemological challenges of PNS modelling is the use of non-equivalent descriptive domains. This is substantiated in Quantitative Storytelling (QST), an approach that evaluates models by quantitatively exploring multiple competing narratives and assessing their plausibility and internal consistency, rather than seeking a single optimal explanation or policy prescription (Fragio & Carpintero, 2024; Giampietro & Bukkens 2022; Saltelli & Di Fiore, 2023; Saltelli & Giampietro, 2017). In essence, QST aims to enhance both the robustness and the epistemic quality of quantitative analysis of complex systems.

3. Questionnaire

Beyond the foregoing analysis, it is useful to compare the findings of our survey on the epistemology of ignorance with the views of several leading scholars in PNS, namely Silvio Funtowicz, Mario Giampietro, Andrea Saltelli, and Kozo Mayumi. These authors responded to a questionnaire addressing the emergence of a new PNS modelling style, the epistemology of ignorance, the challenge of relativism in model building, and criticism of integrated assessment models (IAM). **Table 2** summarizes their responses. Moreover, their answers contribute to clarifying and deepening the issues discussed above.

Table 2. Summary of the questionnaire

Question	Funtowicz	Giampietro	Saltelli	Mayumi
1) Does Post-normal science involve its own modelling style?	Yes	Yes	Yes	No
2) If so, what are the main features of post-normal modelling?	The focus on quality through the extended community of peers.	A relational analysis to check impossibilities using different numbers within different representations of a given issue while keeping coherence among them.	Post-normal modelling proceeds "via negativa" by identifying bad practices.	-
3) Is epistemology of ignorance a factor of de-idealization of models?	-	Acknowledging the unavoidable presence of ignorance in any representation is essential because it forces to acknowledge the relevance of the moral responsibility of the scientist.	Any epistemology that ignores ignorance is an intellectual fraud.	-
4) Does relativism constitute a problem for model building?	Ambiguity and relativism should not be confused. Ambiguity is the characteristic that defines complexity. The multiplicity of perspectives is not relativism but complexity. It is part of the uncertainty and indeterminacy of the system.	Absolutely, no. What is a problem for modelling is ignoring that everything is relative. Complexity simply requires accepting that we are modelling "names" and not real entities.	Relativism — in the sense to consider a plurality of epistemic and normative positions— becomes a hindrance if one wants to take advantage of the epistemic authority that descends from building a large model.	-
5) Integrated assessment modelling (IAM) involves epistemological flaws? If so, what are they?	-	The integrated assessment provided by IAM is a legacy of the intoxication of the economic narratives framing the discussions over sustainability.	The appetite of experts for fantastic numbers and ludicrous precision has not gone away.	-

Source: Funtowicz, Giampietro, Saltelli & Mayumi (email communications).

Silvio Funtowicz agrees that PNS entails a distinctive style of modelling. According to him,

> "[...] its main feature is the focus on quality through the extended community of peers. The model must be fit for purpose, resulting from a social, political, and institutional process. In this sense, the model is considered a hypothesis to be tested in a participatory process with the extended community of peers that defines the problem, the appropriate knowledge, the role of the research, and evaluates its quality. The community is part of the research process and its eventual resolution. It is the arena where conflicts of values, interests and power differentials are expressed".

According to Mario Giampietro,

> "PNS introduces an epistemological revolution in the way we should do science. Getting out of the Cartesian dream of prediction and control, in which the analyst was supposed to be outside the observed phenomena (so the scientist could pick up a descriptive domain based on the use of only one dimension and level of analysis), in PNS is acknowledged the fact that we are inside what we are observing. This entails that we cannot assume a given (uncontested) definition of what is the system that we are observing. We can only represent 'specific perceptions' of the external world, BUT not the world itself. This is an old distinction coming from Oriental religions between 'the NAMED' –what we are representing using symbols– and 'the TAO' –the external world that we cannot know in all its possible aspects (dimensions and scales of analysis)–".

As Box and Draper (1987) famously observed, "all models are wrong, but some are useful". For Mario Giampietro,

> "[...] the usefulness of models depends on the relevance and pertinence of the preanalytical choice needed to make any formal representation: (i) what the system of interest 'is' and 'does' in the representation; and (ii) a hypothesized causal relation among events, which is supposed to explain observed changes. Narratives are devices for constructing mutual understanding between the storyteller and the listener. All those accepting a given narrative and using a given model must agree on: (i) the relevance of the selected narrative for their common good; and (ii) the efficacy of the analytical representation of events and causality associated with the given narrative. The problem with complexity is that there are always multiple non-equivalent legitimate narratives that can be applied to a given situation determining the coexistence of legitimate

but contrasting perceptions about purposes and concerns. In this situation, the use of numbers generated within a single model based on just one of the possible pre-analytical choices of scale and dimension is dangerous. An alternative to this impasse is represented by relational analysis calculating different numbers generated within non-equivalent representations (models, narratives). Relational analysis can study the existence of impredicative relations when observing complex phenomenon that can/must be observed across different scales and dimensions of analysis – i.e., chicken-egg paradoxes. Relational analysis allows us to do a robust integration of relevant information referring to non-equivalent narratives about a given event when considering different concerns and time scales. The logic of relational analysis is different from the logic of conventional quantitative models.

For example, let's assume that we have 1,000 people (X) eating 500 kg of grain per capita per year (Y), and we want to know the quantity of grain to be supplied per year (Z) to support their diet. Within this narrative the answer can be obtained using a simple equation:

X x Y = Z → 1,000 people x 500 kg p.c./year = 500,000 kg/year of grain.

However, if we change the narrative, we can imagine having 1,000 people and an external constraint (a given amount of land in production) limiting the available supply to only 300,000 kg of grain/year. Again, we can use a simple equation Z/X = Y to study the consequences of the forced relations over numbers, within this new narrative: 300,000 kg/year / 1,000 people = 300 kg grain p.c./year. In this second narrative, each individual has available only 300 kg of grain per year. Assuming the constraint considered in the second narrative, either the 1,000 people will have to reduce their consumption of grain to 300 kg of grain/year (e.g. by becoming vegetarians) or they will have to migrate (400 people will have to move to another area) or they have to introduce new techniques to grain production improving the yields.

Obviously, in relation to food security we can add other the narratives related to other relevant aspects to be considered in a quantitative analysis:

1. the nutritional quality of the diet - using quantities expressed in kcal/day looking at the mix of nutrients, rather than in kg of food products;
2. the implication of the type of diet – i.e., a vegetarian diet or with different levels of meat;
3. the mix of crops cultivated in the agricultural sector – i.e., kg of food commodities such as pork, beef, poultry (including the feed), potatoes, corn;
4. the mix of techniques of agricultural production – i.e., quantities of agricultural inputs such as kg of fertilizers, kg of pesticides, hours of work, cubic meters of irrigation, etc. analyzing patterns in the mix of production inputs;

> 5. the availability of natural resources – cubic meters of water abstracted from the aquifer, hectares of available land, etc.
>
> 6. the dependence on import – lack of food sovereignty.
>
> All these different metrics can be integrated into an overall grammar guaranteeing congruence over the accounting across the different lenses of analysis. In this way, we can identify stories that are plausible when events are observed within a given lens, but that are implausible in relation to at least one of the representations associated with the use of different lenses. Quantitative Story-Telling, in sum, does not make predictions, but it checks impossibilities".

For his part, Andrea Saltelli emphasizes that "PNS is rarely openly prescriptive. It rather proceeds 'via negativa', by identifying bad practices such as determinism, economicism, solutionism, reductionism, excess precision, or displacement (Rayner, 2012). PNS is indeed about 'defogging the mathematics of uncertainty' (Funtowicz & Ravetz, 1990)." Regarding the defining features of PNS modelling, "one can mention the emphasis on participation and the extended peer community, where models become a learning instrument or a metaphor (Ravetz, 2003). The 'Manifesto' (Saltelli *et al*., 2020) can be said to be inspired by PNS, but without pretention to become a doxa, in the sense of 'these and only these are the rules to follow'".

Kozo Mayumi does not think that the post-normal approach "suggests any form of modelling". If one keeps in mind the modelling relation proposed by Robert Rosen (1985), what really matters is the process rather than the specific instance of the model. In this respect, Giampietro recalls Leslie White's distinction between "science" and "sciencing" (White, 1938). "When explained in this way, the predicament is how to guarantee quality to the process used to generate families of non-equivalent models dealing with the same sustainability issue". In this sense, Giampietro points out that the

> "difference between models and PNS modelling should be clearly stated. PNS modelling means checking the robustness and relevance of the different narratives underlying the generation of non-equivalent models. [...] Given a perception of a natural system in the external world, in order to generate a formal representation of it with a formal system of inference we have to: (i) encode our choice of relevant attributes into proxy variables; and then after having used the model (ii) decode the results into predictions about what will happen in our original perceptions that will result useful to guide action. This means that our choice of coding and decoding is not related to 'the perception' nor to 'the representation', but rather to the identity of the analyst and to the reasons why the model is generated and used. So, it is the generation and the use of the model that has to be contextualized to check its quality. It is the narrative (our choice of encoding and decoding for explaining causality in the anticipatory system) that defines the usefulness of the model. Consequently, PNS modelling is about the selection of: (i) narratives, (ii) proxy variables, and (iii) the identification of causal relations to be described by an inferential system". Giampietro concludes "it is this process that matters, not the model. When coming to Quantitative

> Story-Telling ('via negativa') the only possible solution for dealing with the unavoidable epistemological challenge of complexity is to try to combine as many relevant selections as possible in the process".

For Giampietro, "acknowledging the unavoidable presence of ignorance in any representation is essential because it forces to acknowledge the relevance of the moral responsibility of the scientist. We cannot define what is 'the best course of action' and this entails that we have (as scientists) to help the society to make informed decisions by explaining the weakness and strength of different narratives". As a result, modellers should not seek to prescribe solutions or "tell society what to do".

Andrea Saltelli notes that the "so-called epistemology of ignorance has a long tradition, and it was already practiced by philosophers from Socrates to Nicholas of Cusa". Following Ravetz (2015a), he states that "any epistemology that ignores ignorance is an intellectual fraud".

With regard to the relationship between relativism and model building, Silvio Funtowicz argues that ambiguity and relativism are often conflated. In his view, "ambiguity is the characteristic that defines complexity. The multiplicity of perspectives is not relativism but complexity. It is part of the uncertainty and indeterminacy of the system".

For Mario Giampietro, relativism does not pose a problem for model building. Quite the contrary, "what is a problem for modelling is ignoring that everything is relative, since we are representing our perceptions gathered in the external world and not the external world. Complexity simply requires accepting that we are modelling 'names' and not real entities in the TAO". Giampietro further argues that "probably 'real entities' in the TAO do not exist, and we can only observe the 'external referent' of the names we use in our language. This is the revolution of complexity against reductionism".

Andrea Saltelli considers that relativism becomes problematic depending on the purposes and positioning of those constructing models:

> "If one wants to take advantage of the political economy of modelling (Saltelli & Di Fiore, 2023) and exploit the epistemic authority that descends from building a large, very detailed 'map of the kingdom' (Borges, 1946) then relativism –in the sense to consider a plurality of epistemic and normative positions– becomes a hindrance. If one wants to be responsible, it does not" (Puy *et al*., 2022).

About the epistemological flaws of IAM modelling, Mario Giampietro finds that

> "the integrated assessment provided by IAM is a legacy of the intoxication of the economic narratives framing the discussions over sustainability. If you have prices, then the economy is operating in a situation of moderate scarcity and there are no problems of

> sustainability. If there is absolute scarcity, then you no longer have prices". In this way, "the idea of studying problems of sustainability using narratives that assume by default that we cannot have sustainability problems is bizarre".

This critique is closely related to what he describes as "the mantra that technical innovations and business models will always save us as the 7th cavalry in the old fashion Western movies".

Andrea Saltelli recalls Funtowicz and Ravetz critique of Nordhaus' model on the economics of the greenhouse effect (Funtowicz & Ravetz, 1994). He notes that "reading this old article against Scoones and Stirling (2020) one deduces that the appetite of experts for fantastic numbers has not gone away. The ludicrous precision of the cost of carbon averaged until 2300 is a sufficient example (Coy, 2021)".

Having presented the questionnaire results, we now turn to a discussion that seeks to clarify the relationships between science, PNS, PNS modelling, and the epistemology of ignorance.

4. Discussion

First, it should be noted that, although there are normal and post-normal conditions under which science and its modelling can operate, scientific knowledge obtained under normal conditions is not invalidated by post-normal conditions. Post-normal reflection and modelling are certainly necessary when addressing global practical problems with significant social implications, which require the organization of scientific knowledge in a transdisciplinary manner. The sociopolitical nature of such problems, their resolution —shaped by various agents, each with different preferences, interests, or priorities—, and the uncertainty and lack of information regarding the consequences of the solutions that might be proposed, motivates the reflection on how scientific knowledge can contribute to the decision-making process in conditions other than "normal". This requires the development of participatory processes in which affected populations, non-experts, and others take part in the development of solutions, and present their arguments and reasons in the best possible way. When evaluating some of the "strengths and weaknesses" of proposed alternatives, scientific knowledge is perhaps one of the best ways to compare them with other arguments that are less valid, based on incorrect or spurious reasoning. There are, however, some limitations to this approach in a post-normal context. We need complementary criteria for determining the quality of different arguments and justifications in order to assist in decision-making and democratic deliberation. In this sense, the extended peer community proposal helps overcome some of these knowledge limitations for making decisions in a post-normal context and in the face of urgent problems.

Joan Martínez-Alier has expressed himself in a similar way in a prologue to a book by Funtowicz and Ravetz: "Laboratory science, which is normal science in Kuhn's sense, remains important. There is no need to change the scientific paradigm, nor is there

any need to renounce Western rationality. Newton, Galileo, or Descartes are not to be attacked in the name of the unknown or of a diffuse religious belief. Quite the contrary, the laboratory aims to determine genetic distances between agricultural varieties, or to verify hypotheses in radiation physics. In contrast, normal applied science cannot be used to evaluate the value of conserving biodiversity or to make decisions regarding the use of nuclear power. Professional consultants, such as nuclear engineers or agronomists, are not helpful either in this regard. The issues are too urgent and the uncertainty is too great. As a result, we are entering the field of PNS, a field where the number of evaluators has been expanded" (Martínez Alier, 2000, p. 13). We should emphasize that this process is not just about democratizing decision-making on important issues, but also about improving the scientific understanding of these issues. According to Funtowicz and Ravetz (1993, p. 753): "The extension of the peer community is then not merely an ethical or political act; it can positively enrich the processes of scientific investigation. Knowledge of local conditions may determine which data are strong and relevant, and can also help to define policy problems".

Despite the fact that the consequences of many proposed solutions may be uncertain and unknown, there is also some scientific certainty about how the world works (i.e., about nature's physical and biological laws), which limits our possibilities no matter what our perceptions are.[5] Since sociopolitical problems have multiple dimensions (social, environmental, economic), there are no optimal technical-scientific solutions, but rather the outcome of community deliberation and participation. Mario Giampietro emphasized this above, when he underlined "the moral responsibility of the scientist". We believe that scientists are expected to contribute their knowledge to collective discussions with other stakeholder groups (extended peer communities), making PNS not just "science *for* the people", but "science *with* the people".

In contrast to some beliefs, we suggest that the dichotomy between facts and values does not disappear in PNS, but rather is *reconsidered*. We maintain that the distinction between facts and values remains valid in PNS, although not in the same sense as in normal science. In the case of nuclear energy or transgenic crops, for instance, uncertainty and lack of quality information make it difficult to accurately predict the future consequences (facts) of the use of these technologies. However, when decisions must be made under such conditions, values play a central role in guiding action (for example, based on the precautionary principle). Thus, the fact-value distinction remains valid and does not vanish, but its role in a post-normal context changes. Funtowicz and Ravetz themselves acknowledge it: "PNS has the paradoxical feature that in its problem-solving activity the traditional domination of 'hard facts' over 'soft values' has been inverted" (Funtowicz & Ravetz, 1993, p. 750).

With respect to the role of the epistemology of ignorance in PNS modelling, this article has examined several categories that are central to a de-idealisation of scientific models

[5] Note that Giampietro reminds that Quantitative Storytelling does not make predictions, but it checks impossibilities.

through a critical analysis of ignorance: “usable ignorance”, the “social construction of ignorance”, “uncomfortable knowledge”, “hypocognition”, and “hegemonic storytelling”. We argue that a distinctive feature of PNS modelling should be the use of the critical analysis of ignorance to enhance the quality and reflexivity of scientific models, given that representations of the target system are inevitably stylized, partial, and approximate.

From this perspective, models participate in the social construction of ignorance insofar as they provide interpretative frameworks through which reality is perceived and understood, while simultaneously privileging certain representations over other possible and equally legitimate alternatives. Furthermore, the exclusion, marginalisation, or suppression of sources of uncomfortable knowledge within modelling practices tends to narrow the range of conceivable solutions, thereby fostering hypocognition and potentially amplifying systemic risks. In this sense, models may also function as instruments for concealing uncomfortable knowledge, reinforcing dominant narratives while obscuring alternative perspectives and sources of uncertainty.

One way to prevent unwelcome surprises is to make explicit and publicly available both what is known and what remains unknown within a model. In this regard, models often travel from one context to another, without sufficient consideration of the circumstances under which they were originally developed. As a result, it is frequently overlooked that assumptions that are reasonable and well-justified in one setting may become inappropriate or even meaningless in another. For this reason, both the explicit and implicit assumptions underlying a model must be carefully identified and scrutinised. These include, among other factors, the scale at which observations were made, the descriptive domain of the data, the parameter values required for the model to function, and the aspects that were deemed irrelevant or excluded from consideration. A model should address the appropriate problem by employing suitable narratives and cognitive frameworks, while remaining attentive to legitimate and meaningful perspectives that may otherwise be overlooked. Because modelers inevitably embed their own interests, biases, methodological preferences, and disciplinary commitments into the models, the epistemology of ignorance should constitute an integral component of the PNS modelling. Incorporating a critical analysis of ignorance helps preserve openness to alternative framings and interpretations, thereby reducing the risk of distortions, exclusions, and oversimplifications associated with dominant or hegemonic narratives.

Conclusions

PNS was proposed to address the challenges that arise when science is applied to policy-making, namely in situations in which facts are uncertain, values are contested, stakes are high, and decisions are urgent. Under these post-normal conditions, traditional reductionist models exhibit significant limitations. Instead, PNS requires forms of modelling capable of incorporating high levels of uncertainty, complexity, and, in some cases, irreducible ignorance. Whereas conventional modelling is primarily grounded in what is known, PNS modelling directs attention to what is poorly understood, uncertain, or fundamentally unknowable.

This perspective challenges traditional distinctions between facts and values, knowledge and ignorance, and experts and the public. Within this framework, we have argued that both scientific models and scientific ignorance are central analytical concerns in PNS. Accordingly, this article has reviewed recent developments in the epistemology of ignorance and explored their relevance for PNS modelling. In particular, we have examined concepts such as “usable ignorance”, the “social construction of ignorance”, “uncomfortable knowledge”, “hypocognition” and “hegemonic story-telling”. Together, these concepts highlight how a critical engagement with ignorance can contribute to improving modelling practices and informing policy interventions based on scientific knowledge.

Furthermore, epistemology of ignorance draws attention to social and institutional dynamics that encourage the neglect of certain facts or the marginalisation of well-established knowledge because of its potential to expose latent conflicts, challenge prevailing assumptions, or reveal the fragility of existing agreements. At the same time, it illuminates how dominant cognitive frames can obscure alternative representations of a problem and privilege particular perspectives over others, including those held by legitimate stakeholders.

These insights contribute to enhancing the quality of modelling practices and should be regarded as an important driver of the de-idealization of scientific models, a dimension that is often underappreciated in conventional accounts of modelling. More broadly, they provide new narratives and analytical tools for advancing both PNS and the epistemology of scientific models. Drawing on our survey and the responses to the questionnaire, we conclude that the epistemology of ignorance should constitute a defining feature of PNS modelling and a key mechanism for promoting the de-idealization of scientific models.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration on the use of AI

During the preparation of this article, ChatGPT was occasionally used as a support tool for proofreading and reviewing the style of the English language. It was not used to generate the content or develop the arguments of the article.

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