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Sustainable Earth Reviews (2023) 6:18
https://doi.org/10.1186/s42055-023-00066-3

Sustainable Earth Reviews

ANALYSIS

Open Access

Learning together: facing the challenges of sustainability transitions by engaging uncertainty tolerance and post-normal science

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Abstract

Current efforts towards sustainability tend to focus on maintaining existing systems and structures, by relying on reductionist approaches to problem solving. Increasingly, there is a call for more effective action in reaching sustainability, not through reductionism (e.g. solutions which reinforce the status quo), but through transformative societal changes and cultural shifts. Despite these calls, widespread resistance to such changes remains. This work discusses one of the underlying causes, namely maladaptive responses to uncertainty.

Uncertainty impacts nearly every aspect of sustainability transformations within a society. There are uncertainties related to the defining characteristics of sustainability, the complexity of sustainability, and to the changing roles and identities of individuals within a society as they transition to sustainability. Furthermore, the process which is increasingly called upon to address these diverse sources of uncertainty, known as post-normal science, introduces novel sources of uncertainty.

Up to this point, many societies' responses to this array of sustainability transitions uncertainty is to respond maladaptively, representing uncertainty *in*tolerance (e.g. denial, dismissal, disengagement), as opposed to adaptive responses (e.g. curiosity, acknowledgement and action). Herein, we describe the sources of uncertainty related to sustainable transitions, the role that post-normal science can play in addressing these uncertainties, and describe strategies to support societies' collective capacity for developing uncertainty tolerance to better engage with the processes required for a sustainable future.

Keywords Uncertainty, Post-normal science, Sustainability, Uncertainty tolerance, Complexity

Uncertainty: a feature, not a bug, of sustainability

True sustainability requires a wholesale reworking of how humans engage and live, generating expansive sources of uncertainty [1, 2]; even the term 'sustainability' provokes uncertainty due to its diverse meanings and interpretations [3, 4]. Stemming from the unknowns required for cultural transformation, and in identifying strategies and approaches needed to achieve sustainable living [5, 6], uncertainty is implicit within sustainability transitions.

In this context, uncertainties are both quantifiable (e.g., risk), and impossible to estimate [2, 7]. These latter irreducible uncertainties are often ascribed to the complexity of the context within which sustainability works

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[8]. This complexity stems from the multiplicity and interdependency of Nature and human systems, and the non-linear interactions between facets of these networks (e.g., globally varied human priorities and values; global economic systems; biodiversity and so on) [1]. The evolutionary adaptations that are made across these elements, within the complex system, mean that predicting the best course of actions to take at any given moment is nearly impossible.

In this way, moving towards a sustainable future, from our unsustainable present, can be considered a 'wicked problem'. Originally described as representing challenging contexts which are difficult to define and solve due to their complexity [9], wicked problems are 'chronic conditions that can be managed more or less well' (pg. 112) [10] – an appropriate term for defining sustainability transitions.

Instead of embracing the uncertainties present in wicked problems, or exploring possibilities within these uncertainties, many contemporary resolutions, strategies, policies, and regulations serve to 'fix' planetary health and human issues in a manner perpetuating the status quo [8]. This is despite widespread acknowledgement that such reductionist attempts are not-fit-for-purpose [11–14]. Such reductionist approaches tend to focus on addressing the quantifiable uncertainties with technical solutions by tackling each singular system component (e.g., financial, or environmental or social), instead of exploring mechanisms for complex holistic change which are required for meaningful transitions towards sustainability [12, 15, 16].

Why do we (individually, socially, and institutionally) struggle against acknowledged needs for change? The answer may be related to the uncomfortable knowledge and extant uncertainties that accompany the transformation that sustainability brings to existing power relations, systems, and structures within a society. Given that institutions and societies are made of individuals, facing uncomfortable knowledge, and managing uncertainty, is required at each level (individual, institutional and societal) to achieve sustainability.

Contemporary responses to uncertainty in sustainability transitions

Rayner [10] suggests that 'uncomfortable knowledge', or knowledge that challenges one's worldview and/or threatens the social norms, accompanies sustainability transitions. We, as a collective community, would need to enter unknown territory, where current social norms, governance arrangements, priorities and values would likely need to change as we transition towards sustainability. Such transformations would generate 'a sea of uncertainty' in the wake of the social order upheaval required for achieving sustainability. Rayner [10] suggests that the typical response to such uncomfortable knowledge is societal resistance or 'systemic ignorance' of such expansive uncertainty – essentially a form of active denial where new knowledge challenging the status quo is suppressed. Both Rayner and post-normal science co-developer Ravetz suggest that this 'social construction of ignorance' [17] isn't, itself, negative [10, 18]. Rather, such practices may be necessary for people to focus on the relevant information and filter out the noise or risk becoming 'mental basket cases' [10].

Rayner suggests that when systemic ignorance is represented by 'structural amnesia', where social groups selectively forget certain historical accounts (usually aspects that threaten group consensus or the interests of the powerful) it is counterproductive in facing 'wicked problems' like sustainability transitions. He argues that when faced with the uncomfortable knowledge that the world we know needs to change, societal responses tend to be maladaptive to this uncertainty. This maladaptive response is represented by 'denial, dismissal, diversion (or decoy) and displacement' (pg. 113 [19]. Practically this can manifest in a variety of ways: 1) confirmation bias, where only information that sustains existing beliefs and institutional arrangements are recognised and valued, or 2) a requirement for a precise and definitive answer in a context that cannot have one, or 3) as an over-reliance on quantification, predictions, and control. Alternatively, Rayner suggests that societies can respond to sustainability-related uncertainties in a more adaptive way—by engaging 'clumsy solutions'. Clumsy solutions occur when communities develop a piecemeal solution or settle on a step forward in the absence of sharing or discussing the values, principles, and priorities behind these decisions. A contemporary example of Rayner's conceptualisations related to uncomfortable knowledge is applied to the natural gas cooking conundrum, and represented in Table 1.

Rayner's conceptualisation of societal' 'systemic ignorance' in the face of sustainability-related uncertainties shares and complements features with what Hillen et al., describe as individuals' maladaptive responses to perceptions of uncertainty [24]. Hillen et al. characterises how individuals respond to uncertainty (e.g. our 'uncertainty tolerance') across three domains: emotional (how we feel); cognitive (how we think); and behavioural (how we act). How we respond across these domains, in Hillen's conceptual model of uncertainty tolerance, is influenced by both intrinsic and extrinsic factors such as our personality, our social status, our culture, and the available resources. In considering these moderating factors on individuals' uncertainty tolerance, Hillen et al., describe maladaptive responses to uncertainty as being represented by 'denial', 'doubt', 'avoidance', 'inaction',

Table 1 Practical example responses to sustainable transitions

This table conveys a practical, but simplistic, example of the concepts introduced in this article. By drawing from contemporary knowledge about natural gas cooking, we illustrate pragmatic and real-world applications for the terms: *uncomfortable knowledge*, *systemic ignorance*, and *clumsy solutions*

Uncomfortable knowledge: Natural gas cooking leads to poor human health outcomes and is environmentally damaging.
Potential Responses
Examples of 'systemic ignorance' (maladaptive responses): Despite there being some evidence [20–22] that natural gas cooking can cause human health risk [21], there is a societal response to do nothing. Governments engage in inaction in the face of this uncomfortable knowledge, and individual citizens choose to continue to purchase and install gas cooking despite mounting evidence and the potential risk. This is influenced by government and individuals' confirmation bias (e.g. "*I don't know of anyone who has gotten ill from gas cooking*"); or from demanding precise evidence linking gas cooking with human health and planetary health ailments (such as randomised control trials as suggested by Balmes et al. in 2023) [23] before steps will be taken to address this (e.g. "*Show me the direct link between gas cooking and climate change.*"). The complexity between the relationships of natural gas, human health, and sustainability means that each of these responses could seem 'reasonable' given the current data
Examples of 'clumsy solutions' (adaptive responses): Governments decide to take the next best step with the current information, by banning installation of gas cooking or heating into new house builds. Governments and researchers work with gas companies and restaurants to identify a way to diversify financial interests to reduce sector impact of the ban, developing policies to support this. There are educational initiatives to help consumers understand the appeal of induction and electric cooking. Government agencies work to support sustainability in sourcing the electric energy. As more data comes in about the relationship between cooking and human and planetary health, the actions to address the challenge adapt and change

and 'decision deferral'. Hillen et al., describe the other end of this uncertainty response spectrum with descriptors such as 'acknowledgement', 'curiosity', 'action', 'decision-making'. Similar reactions are observed in research on disasters and risk perception [25, 26], suggesting that the Hillen model may be applicable to sustainable transitions. In this way, considering Rayner's societal perspectives in coping with uncertainty, alongside Hillen's individualised perspectives, could help with a more holistic understanding of the variety of potential responses observed when faced with the uncertainties provoked by sustainability transitions – as well as an awareness of the moderating factors influencing these responses.

Importantly, evidence from different fields suggests that humans' uncertainty tolerance is contextual and changeable, with moderating factors influencing the extent to which we are more or less tolerant of the uncertainty [24, 27–31]. In the case of sustainability transitions, a moderating factor in societies' capacity for uncertainty tolerance (for both individuals and communities), which influences engagement with the unknowable changes that will come, may be the stakes of the decisions made. The knowledge that one's current choices and lifestyles are costing lives, and putting ecological and human systems at risk is uncomfortable, and the uncertainties facing society in considering a sustainable way of life are great. In other words, moving towards sustainable living is high stakes and complex, as it challenges the existing systems and structures that people find comfort, security [32], and certainty in [33]. Our collective response has been, thus far, dominated by: denial, disengagement, and seeking (impossible) certainty through control, predictions and modelling to alleviate the discomfort of the uncomfortable knowledge that accompanies sustainability transitions [34, 35].

There is evidence that these maladaptive responses to the uncertainty that such uncomfortable knowledge brings are ineffective (even dangerous) in us moving, collectively, towards sustainability [33]. When people let uncertainty *in*tolerance dominate, they may close decision-making processes prematurely [36], be less able to engage critical thinking skills [37, 38], and less able to identify and adequately address the uncertainty. This, in turn, results in less robust resolutions to the current polycrisis (ecological, economic and social) our world is facing [39]. For instance, focusing on certainty in planetary health can blind us to rare or unique events (e.g. black swans [33, 40]) that can be potentially catastrophic, or result in 'overconfidence' where policy makers extrapolate the fragmented findings from research directly to, for instance, climate change, ignoring the situated complex system within which climate change occurs [33]. The resulting oversimplification, as in the case of complex biodiversity calculations, may be incorrect or misleading. An example of this is represented by fishing and hunting quotas [33, 41, 42], where oversimplification of the complex ecosystem can lead to overfishing. In each of these instances the tendency is to hyper-focus on the calculable uncertainties at the expense of expanding our preparedness for the irreducible uncertainties. Though it is these latter uncertainties (uncomfortable to our bureaucratic style of governance which privileges quantitative information) that would be necessary to embrace in order to upend the status quo towards sustainability [8, 13, 43, 44].

There is an alternative approach to managing sustainability's numerous sources of uncertainty, one that supports curiosity and 'clumsy solutions'. A growing movement known as post-normal science (PNS) provides insights for guiding societies' adaptive responses to sustainability-related uncertainties [45, 46]. Globally PNS is gaining increasing recognition [47, 48], but it is important to consider that the process of PNS introduces novel sources of uncertainty [15, 49–51]. Thus, strategies which support societies' collective capacity for uncertainty tolerance are becoming increasingly necessary to help our communities adaptively manage the uncertainties of PNS, and the uncertainties provoked by societies transitions to a sustainable future.

Post-normal science: an old(er) idea for contemporary challenges

Historical Western accounts of science research (e.g., 'normal' science) centre on hypothesis-driven explorations largely made up of a series of linear, sequential investigations, and reductionist approaches [52]. These inquiries, often stemming from a positivist paradigm [6, 53, 54], start with the notion that complex systems can be broken down into constituent components, independent of context and our bodies. These fractured parts are then studied, with resultant findings extrapolated back to the system under study. This type of complexity reduction necessarily ignores that the whole typically does not directly equate to the sum of the parts. While this approach is appropriate in many contexts, such scientific approaches largely represent a maladaptive response, or 'systemic ignorance', when society is faced with 'wicked problems' because such scientific approaches tend to ignore that humans are an integral part of the of the sustainability predicament. As Matthias Kaiser wrote (translated, p121):

> *"Normal science is typically not so good when it comes to being concrete and specific: Our theories are simply not designed to deal with complex singularities, but rather with simple generalities" [55].*

Normal science also relies on collected evidence overtime, a consensus of the scientific community, and often occurs in a 'controlled' environment. The impartiality of normal science, resulting from the separation between the investigated question and the values of the research community, is cited as directly opposing what is needed to move towards sustainability as Jebeile and Roussos comment [56]:

> *"Physical science is traditionally conceived of as an impartial, neutral, and autonomous epistemic enterprise [57]. These are elements of the stereotype of the objectivity of science. It is impartial in that scientific practice takes place with reference only to epistemic values (such as improving accuracy, and in contrast with "non-epistemic" values like pursuing justice.) It is neutral in that scientific results make no value statements (e.g., about what society ought to do). It is autonomous in that science's sole goal is to increase knowledge; values do not determine the research agenda. **However, operating impartially, neutrally, and autonomously is in tension with producing knowledge that is usable."**(Author bolded; Pg. 3)*

In the context of societies' transformation towards sustainability, normal science's focus on definitive, objective answers means that knowledges created outside of the boundaries of scientific disciplines are often considered less relevant, or even irrelevant. Indeed, there are some that question the value of normal science's ability to explore the natural world [14], as many of these scientific approaches are increasingly removed from nature and instead represent artificial simulacrums [58, 59].

Sustainability is a complex system process where human culture and economics, ecosystems and geography, politics, priorities, and values are all entangled; changes are influenced by, and influencing, different elements in a dynamic, evolutionary, and unpredictable way. Studying each part individually, in a laboratory setting or through some types of computer simulations, while valuable for understanding the individual component, does not always provide the needed insights into the complexity of the systemic changes accompanying sustainability transitions. Nor does separating the values and priorities of global societies, cultures and ecosystems when considering sustainable practices, as it is these values and priorities that may be driving some of the relevant complex processes. Wilber's 'Integral Theory' argues that such complex systems should consider four components in identifying solutions: 1) the individual's cognition; 2) the community's perspectives; 3) observable behaviour; and 4) societal systems and organisations [60, 61], and thus argues for acknowledging the role of humans in solving wicked problems. Some areas of science, such as systems science, are already embracing the entanglement of sustainability [62, 63], but more can be done. A problem-solving strategy for guiding scientific approaches to wicked problems, one which considers both the complexity and the human role in contributing to and addressing the problem, may be found in post-normal science (PNS). Post-normal science embraces expansive sources of information and complexity.

Extending from the historical Western 'normal science' described by Kuhn [64], post-normal science (PNS) is a problem-solving strategy predicated on the idea that modern scientific approaches are not appropriate for addressing real-world complex challenges,

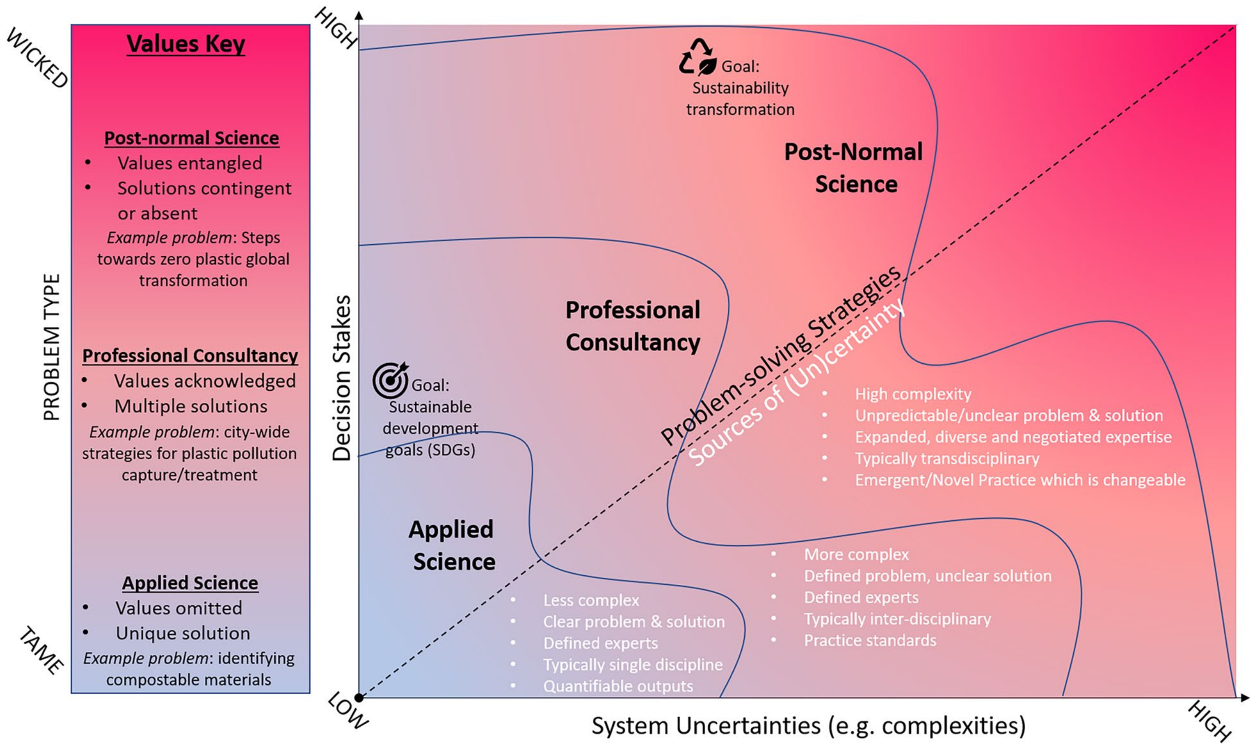

Fig. 1 Factors influencing problem-solving strategy selection. As decision stakes (y-axis) and/or system uncertainties (x-axis) increase, post-normal science's (PNS) application to problem-solving also increases. These problem-solving strategies serve different goals (above dotted line) related to sustainability, introduce different sources of uncertainty (below dotted line), and incorporate different values (left hand side). The example of scientific approaches for addressing 'plastic pollution' is included to illustrate the impact of values on problem-solving strategies

particularly when stakes and/or uncertainty are high (Fig. 1). The goal of PNS is to "make our ignorance usable" [65] (pg. 141), thus PNS embraces and engages uncertainties. PNS does not seek to hide the unknowns away through systemic ignorance, but instead promotes processes which identify the uncertainties, focusing on the quality of knowledge inputs to policy decision-making and political action.

In normal science, truth is determined, understood, and communicated by an exclusive peer group – scientists; and those outside of this group are often not considered (at least not directly) part of the process of problem definition, knowledge creation credibility, or quality evaluation. While some evidence suggests that changes in normal science are afoot, with the inclusion of consumer or community partners through co-design processes [66, 67], normal science still has a limited capacity to address the complexity, uncertainty and stakes of the current acknowledged challenges related to sustainability transitions [13].

While PNS was designed to address the uncertainties in policy-related research, PNS can also be applied to uncertainties emerging from required societal transformations towards sustainability. Regardless of context, engaging in PNS also introduces new uncertainties related to: Expertise, research context, the researcher's role, the approach to disciplinarity, methods engaged, and anticipated outcomes [50, 51].

Contrary to expertise restricted to the scientific elite, an integral element of PNS is the 'extended peer community' (EPC) [15, 45, 46, 65]. The inclusion of an EPC results from recognition that complexity implies irreducible ambiguity, and a necessity for many distinct modes of description of a system [68], such as those described by Wilber's Integral theory. Thus, diversity is paramount in the EPC, and in many cases this includes 'expertise' from those beyond the scientific community. Within the PNS framework, the EPC contributes valuable expertise including local knowledges and lived experience. Such expertise is often unpublished and based on a different value set than is typical of normal science. Post-normal science challenges us to reconsider definitional characteristics of both credibility and legitimacy in the research process by arguing for a democratization of expertise and a de-centralisation of knowledge.

Importantly, the EPC isn't meant to represent a group receiving charity from expert scientists. Rather, for PNS to be fully realised, all involved EPC parties must engage in a manner that results in a new collective way of thinking and doing – a novel (and arguably more complete) understanding of the situated complex system being explored. For this reason, even engaging in research processes which allow for reflexivity on the positioning of the researcher in relation to the research and researched (e.g. ethnography; standpoint epistemology), does not fully represent a PNS EPC. This is because the researcher often remains an 'observer', learning from the participants, and sitting in a position of power in relation to the participants 'giving' knowledge [69]. Furthermore, these reflexive processes, on their own, often stem from a core tenant that research can be objective, and that reflexivity allows for transparency about how the researchers' viewpoints could 'colour', 'bias' or affect the research process and interpretation [69]. In PNS, values are inseparable and integral to the problem-solving process (Fig. 1), and while reflexivity can be part of developing an EPC, it does not fully replicate it. Thus, a source of uncertainty in PNS is in the re-defining of expertise, knowledge holders, and the ensuing challenges in understanding an individual's role and power relations within the EPC. Recognising the value of diverse experiences and knowledge in addressing complex problems, elements of the EPC are increasingly incorporated in more traditional scientific approaches through such practices as participatory modelling in systems science [70], design thinking in healthcare [71], or in the engagement of citizen science [72].

Additional sources of uncertainty related to PNS include the plurality of knowledges relevant for adequate exploration of trajectories towards sustainability. An illustration is provided by Whiting et al., in their diagram on pg. 33 [73] which depicts the following: climate is influenced by human activities, and as these change due to sustainable practices (or the failure to engage in them), human activities will also change (e.g. migration, development etc.) in a sort of cyclical, but largely uncertain, manner. However, the interactions of this complex system go way beyond this single human dimension – there are factors such as greenhouse gases, terrestrial ecosystems, ocean biochemistry, politics, cultural rituals and so on that all play a role how the planet responds to human activities, and vice versa. For this reason, PNS embraces a transdisciplinary approach which is operationalised, in part, through the EPC. But among scientists (or knowledge holders) of different disciplines there are varied priorities, worldviews, languages, and methodological approaches [54]. Thus, the transdisciplinary nature of PNS introduces further uncertainty [50, 51, 74].

Another dominant source of uncertainty when engaging a PNS approach towards sustainable practices across societies is the innumerable directions that the PNS journey can go. With PNS, the approach is focused on using available information (including that which the EPC contributes) and identifying the next agreed best step (e.g., a clumsy solution), not in identifying the (arguably impossible) definitive solution (Table 1). Those engaging with PNS must remain cognitively flexible, avoid 'sunken cost fallacy' (where people tend to continue down a path because they have already invested resources) [75] and change direction as processes mature, new information comes in, and trust develops. This nimbleness is a core tenant of PNS, as PNS centres on adaptive decision-making processes. Ultimately, as Ravetz states [76], we can no longer separate 'nature', 'science' and society'. The PNS framework – by engaging the EPC and transdisciplinary approaches—seeks not to have *the* answer, but to identify the next step to take in the current context, and makes provisions for changing direction as the system changes.

However, without proper preparedness for managing uncertainty, the breadth of additional uncertainties that PNS introduces could result in drive towards furthering 'systemic ignorance' and entrenching maladaptive responses. By improving our collective uncertainty tolerance, we may be more likely to embrace the uncertainties related to PNS, and the uncertainties of sustainability transitions.

Developing our uncertainty tolerance to engage in Post-Normal Science

The predominate sources of uncertainty introduced when engaging in PNS are tied to one's personal and professional identities, and one's roles within an existing societal and institutional framework. When tackling sustainability transitions, individuals are being asked to redefine who they are within a given society (e.g. roles and definitions of expertise/legitimacy/credibility) – this generates uncertainties about social norms, values and priorities. These social uncertainties appear to be contributing to a societal 'identity crisis' [77, 78] and impacted, at least in part, by the tragedy of change [15, 79].

Societies can move towards embracing the potential advantages of PNS in supporting sustainability transitions by developing a shared capacity to evolve our collective thinking towards uncertainty tolerance. This includes recognising the conflicts resulting from changes in the balances of power, and the uncertainties provoked in challenging the status quo. Without this, full engagement with PNS is likely to be stunted as Friedrichs et al. notes in their 2011 article [80]:

> *"On the one hand, extending the peer community has intensified debate and galvanized part of the public for action. On the other hand, important sectors of the public do not forgive any dilution of scientific rigor – especially with regard to "inconvenient*

> *truths." This imposes upon scientists a difficult balancing act in which they must invoke scientific objectivity to maintain authority [when engaging in post-normal science]" (pg. 472)*

In such scientific and societal identity crises, where we are redefining truth, knowledge and expertise, we can face this uncertainty with curiosity and wonder (e.g., uncertainty tolerance), or with denial, frustration, and rejection (e.g., uncertainty *in*tolerance/structural amnesia). A theory that can help us better understand the spectrum of responses to the uncertainties related to our social identities when engaging PNS is known as 'uncertainty-identity theory'.

Uncertainty-identity theory, whose first description is attributed to Hogg and Adelman [81], seeks to explain how we manage and/or align with different social groups or teams. Hogg defines the core tenets of this theory below [82]:

> *"The core tenets of the theory are (a) that feelings of uncertainty, particularly uncertainty about or relating to who one is and how one should behave, motivate behaviors aimed at reducing uncertainty, and (b) that the process of categorizing oneself and others as members of a group effectively reduces self-uncertainty because it provides a consensually validated social identity that describes and prescribes who one is and how one should behave." (Pg. 338-339)*

In the context of normal and post-normal science, following Hogg and Adelman's rationale, there are those in the 'in-group' and the 'out-group'. Those in the normal science community could see those engaging in PNS, or those in the EPC, as outsiders – viewing themselves as insiders. This would generate pressure for those in the PNS outgroup to engage in normal science activities (e.g. 'objectivity' [80]) to fit in, to be heard, and to be taken seriously. Ravetz (2004) states "*in many ways science inherited the dogmatism of the literalistic religious world-views that it supplanted*" (pg. 355), suggesting that the historic normal science system is a defined social group, as any religion would be. In this way, PNS could generate 'uncomfortable knowledge' for those in the normal science 'society', as it challenges and disrupts the way in which such modern states create, understand, and use knowledge [58, 83].

By challenging existing norms, priorities and values, PNS may generate uncertainty for those in the normal science group, resulting in a strong desire for this group to reduce this uncertainty. According to uncertainty-identity theory [81, 82, 84, 85], these feelings of self-uncertainty (due to questioning core values, priorities, structures and identities) result in an overwhelming desire for certainty, to reduce the feelings of discomfort that accompany this destabilisation of 'truth'. The result? Those within the normal science social group may tend to 'double down' on what 'counts' as science, often reinforcing (with certainty) what the prevailing social identity is – that only scientists have requisite expertise and credibility; that knowledge outside of peer-reviewed and controlled study environments is not legitimate [86]. Normal science, and the Western societies built upon it, can engage structural amnesia to stamp out the uncertainties PNS elicits. In doing so, the openness to new ways of approaching crises (e.g., PNS) or cultural transformations towards sustainable practices are 'shut down'.

There is an alternative, however. We can develop our collective capacity to tolerate the identity-uncertainty that accompanies PNS through uncertainty tolerance capacity building. By being able to more effectively manage the discomfort and destabilisation that accompanies challenging the existing and established scientific social order (e.g., facing the uncomfortable knowledge), we will be more readily able to listen to, understand, and value the knowledge and expertise of those outside the scientific community, and support effective engagement with PNS to develop the clumsy solutions necessary to move towards sustainability. We may, also, be less likely to view normal science and PNS as distinct and competing ideas, and more likely to embrace PNS for what it is: a fit-for-purpose scientific approach for a context where the stakes and/or uncertainty are high.

Evidence from healthcare supports the idea that developing our uncertainty tolerance can help us expand our perceptions of who carries legitimacy and credibility with knowledge. Studies in this sector suggest that healthcare providers who are more uncertainty tolerant tend to be more able to engage in person-centred care (e.g. acknowledging the expertise of the patient in their own care), than those who are less tolerant. Alternatively, practitioners who are less tolerant of uncertainty are more likely to approach patient care paternalistically or with culturally illiterate practices, by making decisions *for* the patient rather than *with* the person seeking healthcare [87–89].

Given the urgent need to move towards sustainable lifestyles, and the challenges we face as a society in doing so, the time to build our collective and systemic uncertainty tolerance is now. There are strategies that both individuals and systems can engage to support adaptive responses to uncertainty and develop our capacity for improving our uncertainty tolerance including: creating spaces that are *psychologically safe*, building *communities of practice*, creating a *sense of purpose*, maintain *curiosity*, and engaging in *reflexivity*. While each of these is discussed in turn below, PNS knowledge-creators are encouraged to engage a multi-pronged approach for managing the related uncertainties in support of building the necessary uncertainty tolerance capacity for effective PNS engagement. Ultimately, PNS is predicated on the idea that learning together, from diverse sources of knowledge, is necessary for sustainability transitions - and this requires a context conducive to plurality [90].

Psychological safety

Uncertainty-identity theory suggests that questioning where you fit in, and what the 'rules are' in society, as occurs with the democratisation of knowledge in PNS, can feel threatening [84, 85]. Post-normal science also requires experimental approaches that are flexible and changeable, producing further uncertainty. Such destabilising contexts can benefit from psychological safety for those partaking in PNS. *Psychologically safe* environments are ones that encourage all ideas and voices, where people are open to giving and receiving feedback with honesty. Such settings foster collaboration, risk-taking and experimentation [91]. Defined by Schein and Bennis et al. [92] as "*the extent to which individuals feel secure and confident in their ability to manage change*." (Pg. 523), psychological safety can help create a group where being "in" is about engaging with uncertainty and seeking change. Thus, psychological safety can foster effective EPC engagement while also providing settings where the risk associated with the self-uncertainty PNS methods produce can be overcome. It appears that leaders play a critical role in the success (or failure) of psychological safety [91]. Within the PNS framework, the knowledge-holder has a re-defined role. In this context, knowledge holders may be focused on creating psychological safe spaces built on 'inclusiveness', 'support', 'trustworthiness', 'openness' and 'behavioural integrity' as opposed to being the person with *the* answer. In this PNS-supportive context, instead of being the knowledge expert, the role of those participating in an EPC is focused on the development of psychological safety.

Community of Practice (CoP)

While the definition of *communities of practice* continues to evolve, herein the authors define these as communities where individuals develop their professional identity, or their perceptions of their roles in the work undertaken [93]. To help manage the self-uncertainty accompanying transdisciplinary work within an EPC, a CoP could be invaluable for re-defining identities and roles within a community from one that is only representative of an elite group to one that legitimises each citizen as a knowledge-holder. Furthermore, an effective CoP could help those outside the elite more readily identify themselves as 'experts' who are able to contribute to problem-solving towards sustainability in a PNS context. A 2009 review suggests four characteristics for effective engagement of CoPs, including opportunities for 1) interaction, both formally and informally, to provide opportunities for exploring how to work together; 2) sharing knowledge to identify areas of strengths and growth; 3) collaboration to 'create new knowledge'; 4) developing 'a shared identity' [94]. Developing a new identity to support EPC formation, through CoPs, which is inclusive of those with local and situated knowledges can help combat the self-uncertainty which can accompany those working 'outside' of normal science or who previously did not consider themselves experts.

Sense of purpose

The lead authors' work exploring uncertainty tolerance in healthcare and education has identified a *sense of purpose* as being a powerful moderator of one's uncertainty tolerance [95], and this is supported by other work exploring the role of identity formation in managing uncertainty [96]. When irreducible uncertainty is high, having a clear motivator and purpose for managing this uncertainty can keep individuals focused and help them adaptively respond to the complexity. This sense of collective purpose, in the case of PNS, can be focused on discovering the power differentials and potential areas of conflict, identifying unexplored opportunities within the uncertainty, understanding the local knowledges through EPC engagement, and/or in identifying and trying uncomfortable trajectories or clumsy solutions. By creating a sense of purpose that is exploratory, as opposed to output driven, the sources of uncertainty become valuable instead of dangerous.

Maintain curiosity

Reorienting away from defining expertise as 'knowing' and 'certainty', towards one that defines experts as those able to identify which questions to ask, those seeking the unknown, and those considering the best approach to listen and hear diverse points of view can support uncertainty awareness necessary for PNS. By entering an EPC activity with curiosity at the forefront, the identity transformation needed to actively participate in PNS is supported, the value of the CoPs are enhanced and society may be more prepared to manage the uncertainties intrinsic in sustainability transitions. Maintaining curiosity, though, is dependent (at least in part) on having a psychologically safe environment to ask questions, and a shared sense of purpose centred on inquisitiveness.

Reflexivity

Engaging in PNS requires us to re-evaluate one's own identity as well as those of the field and of the culture and society within which one lives. A good place to start this process is by taking stock of one's current worldviews, and then regularly engainge reflexivity to acknowledge the process of identity shifting that occurs as PNS progresses, and as individuals across a society move towards a more sustainable future. Indeed, transformative learning theory, where new way of thinking and doing are developed through education, are initiated by encountering destabilising events or uncomfortable knowledge which introduces uncertainty [97, 98]. For the full transformation to take place, where new knowledge is incorporated into the way one views and interacts with the world, depends on engaging with critical reflection [97, 98]. Reflective diaries as an individual or collective discussion within a CoP to explore the developmental process towards redefining worldviews and identities can help foster reflexivity supportive of managing PNS-related uncertainty [28, 29, 95]. During this process acknowledging one's thoughts about the work being undertaken towards a sustainable future, one's worldviews, and preferences can help create space for alternative worldviews, previously unconsidered ideas, or the seeding of clumsy solutions.

These recommendations for addressing the uncertainties are not exhaustive and will need to be revised as we continue to learn how to design quality PNS processes in support of societies transformation to sustainability. These experiments will result in failures and errors, which will strengthen society's uncertainty tolerance – provided we create the context for accepting these failures and errors as necessary steps in the journey of success towards our goal of sustainability.

Policy & practice changes

1. Sustainability represents a complex system, and requires uncertainty awareness.
2. Post-normal science (PNS) is appropriate when uncertainty and/or stakes are great, as with sustainability transitions.
3. PNS requires challenging existing societal structures/systems, introducing additional uncertainties.
4. Effectively managing uncertainties is critical for sustainability and the practice of PNS.
5. Creating inclusive, diverse and psychologically safe spaces can help support PNS.

Acknowledgements

The first author wishes to acknowledge and pay deepest respect to the peoples of the Kulin Nations as the traditional owners of the unceded lands on which this author contributed to the ideas of this work. These lands are sacred, and I (MDL) acknowledge that sovereignty has never been ceded. I (MDL) acknowledge that I come from a history of occupiers who have yet to reconcile with the people or land which was and/or is occupied. I (MDL) respectfully recognise Elders past and present, and acknowledge the many ways in which different cultures and communities perceive knowledge, and thus uncertainty. The authors would like to also thank Laura Gutierrez-Bucheli for her critical review of this paper and raising awareness of the Wilber Integral theory, and to Associate Professor Simon Angus for critically appraising our discussion of complexity theory and science.

Authors' contributions

Both authors (MDL & SF) made substantial contributions to the conception of the work, including drafting and revisions. MDL lead drafting, with SF contributing significantly to revisions and final draft. MDL and SF deep knowledge of the primary theories discussed in this article were equally necessary for the conception of this work. MDL and SF have both approved the final version, and have agreed to be personally accountable for their own contributions.

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Funding

Not applicable.

Availability of data and materials

Not applicable.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

MDL is the author of "The Uncertainty Effect: How to Survive and Thrive through the Unexpected". This book does include related concepts and is available for purchase.

Received: 8 September 2023 Accepted: 7 November 2023
Published online: 13 December 2023

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