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Uncertainty, Risk and the Open Future: Science Education and the Contemporary World

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Abstract

This article discusses how the modern idea of "progress", understood as an improvement in the average material conditions of life, comes into tension with the contemporary production of risks and the expansion of uncertainty. From the framework of the "risk society" (Beck) and "manufactured risks" and reliance on specialized systems (Giddens), it is argued that many current threats are difficult to perceive objectively due to their invisibility, speed and emergent nature. Implications for science education are argued: to train citizens capable of assessing risks, deliberating in scenarios of uncertainty and understanding the limits and scope of specialized knowledge in public decisions.

Keywords: science education; risk society; manufactured risks; uncertainty; trust in science; open future.

Incertidumbre, riesgo y futuro abierto: educación científica y mundo contemporáneo

Resumen

Este artículo de reflexión analiza cómo la idea moderna de «progreso», entendida como la mejora de las condiciones materiales medias de vida, entra en tensión con la producción contemporánea de riesgos y con la expansión de la incertidumbre. A partir del marco de la «sociedad del riesgo» (Beck) y los «riesgos fabricados» y la confianza en sistemas especializados (Giddens), se argumenta que muchas amenazas actuales son difíciles de percibir objetivamente debido a su invisibilidad, rapidez y carácter emergente. Se defienden las implicaciones para la educación científica: formar ciudadanos capaces de evaluar riesgos, deliberar en escenarios de incertidumbre y comprender los límites y el alcance del conocimiento especializado en las decisiones públicas.

Palabras clave: educación científica; sociedad del riesgo; riesgos fabricados; incertidumbre; confianza en la ciencia; futuro abierto.

Incerteza, Risco e Futuro Aberto: educação científica e Mundo Contemporâneo

Resumo

Este artigo de reflexão discute como a ideia moderna de “progresso”, entendida como melhoria das condições materiais médias de vida, entra em tensão com a produção contemporânea de riscos e com a expansão da incerteza. A partir do quadro da “sociedade do risco” (Beck) e dos “riscos fabricados” e da confiança em sistemas especializados (Giddens), argumenta-se que muitas ameaças atuais são difíceis de perceber objetivamente devido à sua invisibilidade, rapidez e caráter emergente. Defendem-se implicações para a educação científica: formar cidadãos capazes de avaliar riscos, deliberar em cenários de incerteza e compreender os limites e o alcance do conhecimento especializado nas decisões públicas.

Palavras-chave: educação científica; sociedade do risco; riscos fabricados; incerteza; confiança na ciência; futuro aberto.

Incertitude, risque et avenir ouvert : l'enseignement scientifique et le monde contemporain

Résumé

Cet article de réflexion examine la tension entre l'idée moderne de « progrès », comprise comme amélioration des conditions matérielles moyennes, et la production contemporaine de risques et d'incertitudes. En s'appuyant sur la « société du risque » (Beck) et sur les risques manufacturés et la confiance dans les systèmes experts (Giddens), il souligne que de nombreuses menaces actuelles sont difficiles à percevoir objectivement en raison de leur invisibilité, de leur rapidité et de leur caractère émergent. Des implications pour l'éducation scientifique sont proposées.

Mots clés: éducation scientifique ; société du risque ; risques manufacturés ; incertitude ; confiance dans la science; Future ouver

1. INTRODUCTION

The emergence of the climate crisis in recent decades has posed challenges that go beyond the boundaries of traditional science and modern political institutions. Today we must admit that human existence is under threat as a result of decisions made in the past. The accumulation of greenhouse gases generated over centuries of industrial activity, mainly by developed countries, has changed the physical characteristics of the atmosphere and altered the energy balance on the planet. The same can be said about the geopolitical scenario, where conflicts could trigger a new world war with the use of nuclear weapons, also capable of extinguishing the human species.

The public's perception of science and technology has been deteriorating along with climate conditions and the inability of the sciences to offer solutions to civilizational threats, as recently occurred in the COVID-19 pandemic. Despite the benefits that have been obtained through science and technology (at least for people living in wealthy and industrialized regions), such as increased life expectancy, clean water, basic sanitation, late modernity has witnessed an increase in public anxiety and fragile trust in science (Gerges, 2025). The denialist movements (Petzold & Nichols 2025) are the tip of the iceberg of a deeper problem, which calls into question the role of scientific rationality in structuring modern society.

There is a great debate about the causes that generated the polycrisis experienced at the beginning of the 21st century. It seems inevitable to admit the partial responsibility of the sciences, and in particular scientific rationality, for the threats faced by humanity. The very idea of "progress", translated into an undeniable improvement in the average material conditions of life, has this universality (Bernardo, Vasconcelos, & Rocha, 2025). This progress, however, has been achieved at the expense of increasing inequality between regions and countries, the concentration of income of companies and individuals, disrespect for local cultures, the degradation of the environment and the quality of life of other living beings (Schöngart, Nicholls, Hoffmann, et al. 2025).

Today we must admit that the project of Modernity has failed to offer a better life for human beings. Modernity, as envisioned by the Enlightenment philosophers of the 18th century, seems more distant than ever from achieving its goals. Stephen Toulmin (1990) considers that the Modern period began in the 16th century with the choice of rationality as a mediator capable of overcoming the incommensurability of the religious and moral disputes that had affected Europe in the previous century. The choice of a society where disputes would be mediated by reason paved the way for peace, but left little room for differences and diversity and imposed a universalizing model on ways of being in the world.

We live in what some call a risk society (Beck, 1992), a society that, in seeking security by transforming the environment through science and technology, has started to manufacture threats that put its survival at risk (Giddens, 1991). This society is characterized by uncertainties manufactured as secondary effects of actions taken in the structuring of social life. In this conception, the use of fossil fuels was an abundant and cheap resource for energy production and enabled the industrial revolution, but as a consequence it generated the gases that have transformed our atmosphere and resulted in global warming.

Life in a risk society generates anxiety in people, as it requires decision making in scenarios of uncertainty, involving imponderable and immeasurable factors that cannot be reduced to zero, either by previous experience or by resorting to experts. In such scenarios, scientific knowledge loses much of its effectiveness in guiding social policies and decisions. This can be seen in the statement made by the UK House of Lords Science and Technology Committee in the Science and Society report: "When science and society cross swords, it is often over the question of risk" (House of Lords, 2000).

Faced with this environment of mistrust in science and high anxiety, it would be worth asking ourselves: is it through more scientific knowledge that we will achieve a just society that distributes social welfare? How can the sciences be used to tackle the various types of problems faced by society? Has progress, both scientific and material, made life safer and people happier?

In this context of civilizational reflection, it is more important than ever to rethink the role of science education. How does science education take part in the project of modernity and how can we rethink it in order to adjust its objectives to a world of manufactured uncertainties?

Answering this question involves understanding the challenges of the contemporary world and being able to conceive a new science education project that allows us to glimpse alternative futures and build the world we would like to live in.

2. THE RISK SOCIETY

Sociologist Ulrich Beck gained fame and notoriety in the early 1990s when he introduced the idea of "Risk Society" to analyze Western post-industrial society. His work sought to connect institutional transformations and challenges with everyday micro-political actions in fields such as health, the economy and the environment (Sørensen, 2018). According to Ianni (2012), Beck presents his theory in three works: Risk Society: Towards a New Modernity (1992), Ecological politics in an age of risk (1995) and World risk society (1999). His thesis is that industrial society, based on scientific and technological knowledge, has started to produce threatening situations. It is important to note that the risk society is one in which catastrophes have become the norm and no longer situations of exception (Beck, 1992, p. 24). It is also important to note that science and technology are the central focus of the discussion proposed by Beck, Giddens and the other supporters of the risk society theory (Mendelson, 2010, p.231).

For Beck, the concept of risk has a profoundly transformative impact on today's society, and has served as a means of better characterizing the contemporary social order (Mendelson 2010). Following this premise, the society that emerges in the post-war period is better characterized by its capacity to produce "risks and burdens associated with technology (such as pollution, nuclear waste, global warming and the side effects of medical treatments)" (op cit., p. 296).

A first interpretation is that industrial societies have experienced important changes as a result of environmental risks, mainly air pollution and radioactive contamination. The growth of this type of risk has led to a disproportionate increase in people's perception of them, changing their beliefs, interests and behaviors.

The centrality of scientific knowledge, lato sensu, in the theory of the risk society brings some specific characteristics to risks and creates constraints on the social means of identifying them. In pre-modern societies and even in high modernity, risks did not require specialized knowledge to be identified, either because of their origins in nature (a storm) or in social functioning (the risk of becoming unemployed). The same cannot be said of today's risks. The vast majority of them remain hidden from most people (such as viruses with the potential to create epidemics, like COVID-19). Risk is often only perceived when it has already materialized into threats with irreversible consequences. One way of characterizing the scientific dependence of risks in late modernity is to consider that threats are defined and formatted by experts. For example, the potability of the water we drink is guaranteed by laboratory tests signed off by a responsible technician. Health tests follow the same validation logic. This means that the risk of being ill depends on standards set by health experts, and can therefore vary over time and from place to place.

Another important aspect is that the increased perception of risk implies a loss of trust in the world. Anthony Giddens explains that the stability of the world is something essential to human existence and is translated into the notion of ontological security (1991). The increase in anxiety can be understood as the result of a growing awareness of the risks that have come to populate people's frame of reference. In other words, risks indicate a weakening of ontological security and place social actors in a state of permanent alertness. In the risk society, the sense of security is, so to speak, lost. The most we can hope for is to deal with risk by relying on people or instances in society that offer us some degree of control over it. Thus, one should not ask about the safety of using a medicine or a means of transportation, but the degree of trust that can be associated with them. In this sense, in the risk society, the danger-safety pair is replaced by the risk-confidence pair.

Today's risks are difficult to perceive objectively, whether due to the speed of events, the invisibility of threats or the inevitable appearance of new risks. This scenario means that individuals are constrained in their lives by risks that are often invisible, but real or even unreal. Climate change, global warming, forest fires, environmental accidents and pandemics are examples that promote these discussions, as part of the population observes and lives with these problems, whether they are global or local in scope (Giulio et al., 2015; Pietrocola, Schnorr, & Rodrigues, 2025).

In this discussion about the new social order in contemporary times, Beck and Giddens' merit was to propose a macro sociological theory focused on the interaction between society and nature. At first glance, one could ask whether risks have actually increased in the new world order, or whether it is only public perception that has increased. For Beck, this distinction makes no sense, because "Both sides converge, condition each other, strengthen each other and, like risks as risks in knowledge, perceptions of risks and risks are not different things, but the same thing" (op. cit., p.55). The blurring of boundaries occurs because, from the perspective of the risk society, what emerges are the risks produced internally within society and whose responsibility falls on humanity. This is what Giddens defines as manufactured risks, which differ from the external risks that have accompanied human civilization since its beginnings (Giddens, 2004). Thus, external risks would be events that can affect individuals and populations, originating outside of modern social life, which happen with some regularity and frequency, being predictable and thus insurable. On the other hand, manufactured risks are generated by the progression of human development, especially the progress of science and technology. They refer to new risky environments for which history has given us very little previous experience, such as terrorism, the reduction of the ozone layer, etc.

In Giddens' work, the concept of manufactured risk is associated with the concept of abstract systems. These are the basis of the mechanisms of space-time disengagement that have modified the way relationships and agency are established in today's society. The abstract system contains one or more symbolic tokens that make it possible to replace objects in face-to-face relationships. Paper money has taken the place of merchandise in commercial relations between individuals, which can be carried out face-to-face. But to be trustworthy, tokens need someone's guarantee. For example, gold, silver or diamonds need to have their purity attested to by someone. In the same way, paper money only serves as an instrument of commercial relations if it is linked to a trusted monetary system. Cryptocurrencies are the contemporary version of the abstract financial system that

would not be possible without computers and communication and information technologies.

Abstract systems allow us to place our trust in social relationships without the need for a face to vouch for them at all times. However, at times the faces behind these systems must appear as a way of reifying trust. We can spend a lot of time traveling by plane without ever meeting an expert who attests to the quality of the aircraft, but at some point we might read, watch an interview or meet an expert who specifies how an aircraft is certified. These moments when abstract systems expose their guarantees in the form of human faces are called access points. The human faces that attest to the guarantees are called expert systems

On the importance of abstract systems, Giddens writes:

"... the nature of modern institutions is deeply linked to the mechanism of trust in abstract systems, especially trust in expert systems. Under conditions of modernity, the future is always open, not only in terms of the ordinary contingency of things, but in terms of the reflexivity of knowledge in relation to which social practices are organized. This counterfactual, future-oriented character of modernity is largely structured by the trust conferred on abstract systems - which by its very nature is filtered through the reliability of established expertise." (Giddens 2004, page 76)

The risk society is characterized as the result of the process of reflexive modernization (Beck, Giddens and Lash, 1994), in which human actions on the environment, both social and non-social, return in the form of latent side effects.

In this way, we can say that two fundamental transformations are affecting people's lives, both connected to the growing influence of science and technology, although not completely determined by them: the end of nature and the end of tradition. In other words, nature can no longer be considered an instance external to society and a source of threat, but is part of the triad of today's world: Nature-Society-Technology. Moreover, its existence is just as threatened as ours. The second transformation concerns the fact that the past is no longer a reliable source of knowledge to guide our actions in the present. In other words, tradition, which has played a fundamental role in social organizations since the earliest times of human groupings, is losing its effectiveness as a guarantor of security in the world. This is because, as society manufactures its own risks, there is an enormous degree of uncertainty arising from situations that have never been experienced or imagined before.

The previous presentation was intended to show how today's society has been modified by the intensive and extensive use of science and technology and how it has changed the world, making it the locus of uncertainty and manufactured risks. Education in general and science education in particular must be able to prepare future citizens to deal with this new world. Generally speaking, no evaluation and decision-making process can be carried out today without taking into account the uncertainty that accompanies every action in a reflexive world.

3. SCIENCE EDUCATION IN CONTEXTS OF MANUFACTURED RISKS

Over the last 25 years, the subject of risk has become part of the concerns of science educators (Levinson, et al 2012). In the Nuffield 2000 report on science education in schools, Millar & Osborne (1998) made recommendations on basic ideals of science and risk:

By considering some current issues involving the application of science, pupils should . . understand the ideas of probability and risk; be aware of the range of factors which can influence people's willingness to accept specific risks. (p. 2022).

In the 2000s, Jenkins called for the inclusion of risk assessment skills as a necessary paradigm shift in science education (Jenkins 2000). Assessing risks is a current societal demand and students should be able to use science to support this. Assessing risks is a current society demand and students, therefore, should be able to use science as support for that. Risk, as places of uncertainty and complexity, are a way for students to bring science into their lives.

Kolstø's (2001) study of socio-scientific dilemmas shows that students question the sources of risk assessment in general on the basis of a relationship of trust in relation to the scientists' position of interest. He also states that the students' analysis is weakly based on their understanding of scientific knowledge or their understanding of the problems when making risk assessments. Levinson and colleagues (2012) deal with decision-making in problem situations involving a fictitious situation described as Deborah's dilemma involving the risks associated with a surgical intervention. Doubles of teachers have to deal with the complexity of the relationship between science-technology and society and decide whether or not to perform surgery, justifying their decision.

Regarding the possibility of dealing with risk in basic education, a number of studies have carried out research involving risk and the ways in which students make decisions (Kolstø 2001).

However, for Christensen there is still a lot of research to be done on the ways in which students understand risk or the role that risk plays in decision-making on contemporary issues in science classes (2009, p. 212). For her, much of the work on risk still looked at it from an externalist perspective, focusing on natural threats and disasters.

For Schenk, Hamza, et al (2019), the great challenge for science education lies in the complexity and dual nature of risk itself, which is both objective (technical knowledge) and subjective (surrounded by values). When addressing risk-based issues or topics, one must consider that these are highly complex subjects, involving a huge number of variables that directly or indirectly influence the problem. Hansen and Hammann (2017) state that the presentation of risk-related topics as simple causal relationships, involving one or a few variables, should be avoided in school science education, as the real-world context is much more complex than this. Also question scientific knowledge as reliable and secure, because in a society of risk, trust comes not just from authority, but from the ability to adjust perception to the multidimensional context of the situation (Christensen, 2009).

Schenk, Hamza, et al (op cit) develop a model to relate subjective and objective characteristics of risk. They propose a multidimensional conception of risk, recognizing

the close relationship between risk and decision-making. Their model includes "activity" as the basis for risk problems, characterized by human actions that lead to risk, but also attitudes to inhibit it; "values" and "knowledge" figuring in the same epistemic niche, interacting and giving subjective characteristics to risk, the former, and objective characteristics, the latter. Despite the parity between knowledge and values, they can weigh differently in risk assessment, considering "uncertainty", "probability", "severity" and "consequence".

Problem-solving has always been the basis of science teaching and acts as a driving force for teaching and learning, since learning becomes more efficient when working on solving real-world problem contexts (Dewey 1916; Wong and Pugh 2001). The importance of problem-solving remains valid for science teaching from a risk society perspective.

Problem-solving is also one of the foundations for developing contemporary citizens in a risk society, as it helps to develop essential skills in the use of knowledge.

However, the risk problems we are discussing here are different from the traditional or "exemplary" ones (Kuhn 1970, afterword). Kuhn's exemplars are problems produced to materialize some pragmatic aspect of a theory. They have some standard solution, agreed upon by scientific communities.

In this sense, during a scientist's training, it is expected that solvable problems will be discussed, once they have been previously validated by the scientific community. Thus, the exemplars function as a way of maintaining "normal science" itself. The exemplary situations of normal science are problems that are already known, allowing for certain solutions and therefore, for the risk perspective we are presenting, they fail.

Exemplars can be considered false problems, in Pólya's (1945) original sense, since they mainly assume the existence of a priori consensual solutions and the question to be solved is how to get students to access these solutions. By bringing this reasoning to science teaching in elementary school, students are exposed to "shared examples" of problem contexts.

Learning is then based on previous conceptual baggage, defined by the scientific tradition, assuming that students will arrive at similar solutions to similar problems. This process also assumes that the students' rationality matrix can be transposed from one context to another (Abrantes, 1998).

Thus, risk and uncertainty completely change the epistemological, ontological and axiological basis of science education, requiring new content, new methodologies and new skills to be learned. It is already possible to see the presence of the theme of risk in some curricula in some countries. In the United States, the Science Education for Public Understanding Program (SEPUP, 2018), for students aged 6 to 12, includes a module on decision-making that deals with the perception of risk and probability. In England, The National Curriculum for England (England 2014) has learning units on risk assessment. In Australia, the Australian Curriculum, Assessment and Reporting Authority (Australian Curriculum, 2014) proposes activities for assessing risk and safety. Also in England, in a compulsory subject for students aged 15 to 16, called Core Science, risk has been included as one of the six ideas about science in the Twenty-first century science curriculum (Millar, 2006).

However, these countries seem to be the exception. The vast majority of science curricula are a long way from incorporating risk aspects among their themes (Christensen, 2009, Pietrocola et 2025).

In the curricular documents mentioned above, although they represent a minority trend, practically nothing is mentioned about the risks generated by the technologies themselves in the terms mentioned by Beck and Giddens. And, generally, the risks are linked to natural hazards and not to scientific and technological development. In a way, curricula incorporate a way of dealing with the role of risks in the scientific training of future citizens that is far out of step with what the emergencies are that make risks so important to study (Pietrocola and Souza, 2019).

4. DETERMINISM AND THE ILLUSION OF CONTROL

An important consequence of the introduction of risk as an inherent aspect of the organization of the contemporary world concerns the ability to control and define the future. The way in which a society conceives causality, freedom and time becomes fundamental in the construction of individuals' imagination and is no longer just an abstract detail: it underpins the way in which we evaluate the future, attribute responsibility to actions and nurture the expectation that reality can be driven by planning and control (Giddens, 1990, 1991).

The philosopher William James formulated what became known as the "Dilemma of Determinism". In a version taken up by Karl Popper in The Unfinished Universe, the dilemma is exposed as the tension between universal causality and free choice:

"Every event is caused by an event that precedes it, so that any event could be predicted or explained... On the other hand, common sense attributes to healthy, adult people the ability to choose freely among several distinct courses of action..." (James, 1897/1956; Popper, 1982).

This formulation shows that the dispute is not only metaphysical, but also anthropological and political: the belief in inviolable causal laws tends to favor the idea that history has a direction that is knowable and manageable by experts; while the ordinary experience of deliberating, choosing and responding to consequences presupposes some degree of openness to the future (Giddens, 1990). By culturally adhering to one of these poles, we define the status of the future (Levrini, Tasquier, Branchetti, & Barelli, 2019). If the universe is strictly deterministic, tomorrow would be inscribed in today, and freedom would tend to be reinterpreted as a psychological appearance produced by our ignorance. If, on the other hand, freedom is real, the future reveals itself as a field of possibilities, continually being constructed by individual actions and collective decisions. The way individuals and societies project themselves in time is therefore profoundly shaped by this belief - whether conscious or not.

Before physics came to solidify a largely deterministic worldview, the human conception of time itself went

through a long historical-cultural journey. Modernity, however, stabilized a specific relationship with temporality by associating it with a narrative of advancement: past, present and future are now organized along an oriented line, in which tomorrow can be better than today (Koselleck, 2004). When this temporality is combined with social and technological acceleration, the future appears less as a field of disputed possibilities and more as a territory to be anticipated, managed and optimized - which reinforces the demand for forecasts, indicators and rapid interventions (Rosa, 2003; Giddens, 1990). Science doesn't just describe the world: it feeds an imaginary of calculability, in which uncertainty tends to be perceived as a temporary failure.

This horizon reached its maximum expression in the ideal of "Laplace's Demon". The hypothesis, formulated at the beginning of the 19th century, states that an intelligence capable of fully knowing the positions, movements and laws governing each particle in the universe at a given moment could reconstruct the entire past and predict the entire future (Laplace, 1814/1951). Historical-philosophical studies show how this image synthesizes, in accessible language, an ideal of total intelligibility associated with the project of classical physics, although the bases and scope of this determinism are the subject of debate (van Strien, 2014).

This horizon was consolidated as a cultural imaginary of predictability based, on the one hand, on classical physics and, on the other, on the idea that, in principle, the future would be contained in present conditions. The temporal symmetry of a large part of the fundamental laws contributed to the idea that equations do not distinguish between the past and the future at a formal level, while the "arrow of time" emerges from specific conditions and processes (Price, 1996; Zeh, 2007).

This scientific conception of time was not restricted to laboratories. It spilled over and shaped practices of government, economics and social organization, holding out the promise that the future, although unknown, would be essentially calculable. Within this framework, complex collective problems are often translated into management problems, and authority tends to shift towards expert systems and technocratic decision-making arrangements (Giddens, 1990; Jasanoff, 2003).

However, modern experience itself reveals cracks in this promise. In non-linear systems, small variations in initial conditions can produce radically divergent trajectories, limiting long-term predictability even when models are deterministic (Lorenz, 1963; Levrini, O., & Fantini, P. 2013). Furthermore, techno-scientific interventions generate side effects and unintended consequences that accumulate outside the immediate field of vision, reconfiguring the problem over time (Beck, 1992).

There is also a decisive element when the object of knowledge involves reflexive social practices: indicators, forecasts and metrics alter behavior, markets and policies, causing knowledge to act on the very system it purports to describe (Giddens, 1990; Espeland & Sauder, 2007). Thus, the notion of control often survives as a normative ideal - and as a source of ontological security - even when the world it is intended to control is, in fact, open, contingent and changing (Giddens, 1991).

It is at this point that the discussion on determinism dialogues directly with the risk society. Technoscience increases the capacity to intervene and, at the same time, the capacity to produce risks of a new order: invisible threats, distributed in time and space, global and hardly attributable to a single cause, often only recognized when their effects are already manifest (Beck, 1992; Beck, Giddens, & Lash, 1994). In this scenario, insisting that the future is fully controllable can postpone prudent decisions in the name of waiting for certainties that will not come, obscure controversies and reinforce dependencies on expert systems, shifting responsibilities to bodies that promise, but cannot guarantee, the elimination of risk (Wynne, 1992; Jasanoff, 2003).

Recognizing the limits of determinism, therefore, does not mean abandoning scientific rationality, but shifting its role: from the ideal of prediction and mastery to the construction of provisional, revisable and socially robust guidelines. This shift comes close to the notion of post-normal science, for which "facts are uncertain, values are in dispute, the stakes are high and decisions are urgent", requiring broader participation and the clarification of assumptions (Funtowicz & Ravetz, 1993).

For science education, the implications are direct: it is a question of forming not only conceptual competences, but also dispositions to deal with uncertainty, understand the limits of models, make values explicit and deliberate collectively about risks and possible futures (Pietrocola, Schnorr, & Rodrigues, 2025; Rosenberg et al., 2022). Perspectives such as "futures thinking" reinforce that responsible agency depends on learning to act with provisional knowledge, considering multiple temporalities and distributed consequences (Laherto & Rasa, 2022). In fields such as environmental risks and disasters, risk literacy proposals also highlight the need to go beyond "technological solutions" and cultivate slower, more reflective forms of learning, capable of sustaining decisions under uncertainty (Park, 2025).

5. FINAL CONSIDERATIONS

The nature that humanity has learned to deal with and get to know since the dawn of its existence no longer exists. At some point in the last 70 years, humanity stopped worrying about what nature could do to it and started worrying more about what it had done to nature. The point emphasized by Beck is that we live in a risk society, which emerged in the post-war period as a stage of reflexive modernity. We are a society experiencing post-nature, a reflection of the techno-science that has transformed nature into techno-nature. In this type of modernity, society's central concerns shift from developing and implementing new technologies to managing the risks associated with existing technologies. In the risk society, the perception of risk has a fundamentally transformative impact. At past moments in history, risk was apparent, and natural disasters constantly tested communities across the globe. In this sense, Beck helps us understand that social institutions are destabilized by the risk of human responsibility. In this way, the essence of risk has been completely modified today, especially in the ecological, political and cultural domains. In this new social order, it is clear that although colloquial usage can create a zone of semantic overlap between danger and risk, these notions belong to very different worlds. In this way, we can

say that two fundamental transformations are affecting people's lives, both connected to the growing influence of science and technology, although not completely determined by them: the end of nature and the end of tradition.

In a way, science education is still linked to an old world perspective. We understand that educating from the perspective of a risk society involves epistemological and ontological changes in relation to the scientific knowledge taught, since knowing and not knowing are superimposed and mediated at every moment by abstract systems that are translucent to us. It also requires a change in axiological perspective, since we shouldn't expect knowledge to provide certain and secure guidance on how to act individually and socially, given that uncertainty is the hallmark of contemporaneity. In most of the challenges faced by individuals, the most we can hope for are more or less accurate predictions about future scenarios and a predisposition to review knowledge and rectify decisions as new evidence emerges. Therefore, knowing which factors are linked to risk perception can help us understand how individuals behave and act in the face of uncertain situations. This point is relevant, since these actions are usually behind decision-making. Threats such as the COVID-19 pandemic and climate change are good examples of how risk perception can affect individuals' behavior and attitudes.

In a 2021 paper, Pietrocola and collaborators developed a matrix for understanding risk perception and the important factors that modulate it. The matrix was structured along three axes: "access"; "scope" and "urgency". Access is associated with rational thinking supported by scientific cognition. Urgency by the hierarchy of individual and shared values in a given culture. Reach by the ability to establish impact assessments, this dimension being strongly mediated by information. Together, they "indicate" the scope of the perception of the risk associated with the situation in focus. The distance from the axes informs about the "location" in local-global terms.

The three dimensions could be understood as coordinates in a "perception space", which could be used with students or groups of students to understand the broadening of risk perception in a certain context (Silva, 2023). The position of the individual or group of individuals in the risk perception space would, on the one hand, be an indicator of developed capacity and, on the other hand, of the need for investment in the development of this capacity.

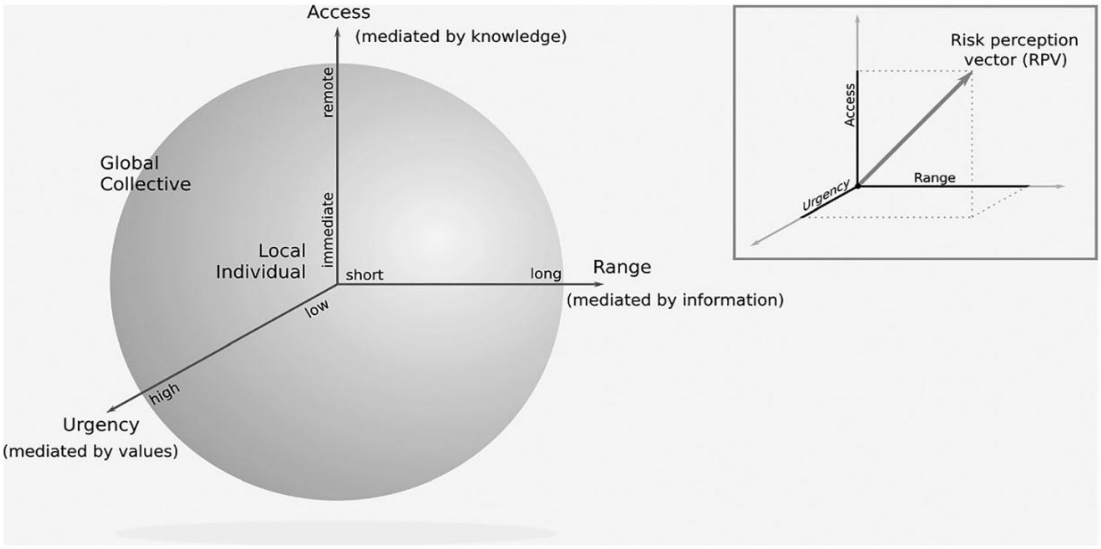

Figure 1: Expanded risk perception matrix. source: Pietrocola et al. 2020, page 222

The axes are not independent, so this is an abstraction that aims to offer a metric capable of positioning risk perception in relation to the scope of risk perception. In order to exercise citizenship in accordance with reflexive modernity, the outer regions of the space of perceptions would be more desirable than the inner ones. Thus, the aim of scientific education would be to broaden perception

The ability to perceive risk situations in a broad way is decisive for success or failure in dealing with threatening situations. And it depends on: awareness of available or absent scientific knowledge; consideration of the impacts of risk on the various dimensions of individual and collective life; evaluation of the information offered by public agents and the decisions they make. It can thus be seen that the perception of risk and the subsequent decision making that derives from it requires much more than a background of predetermined scientific content and an immediate common sense of the effects and impacts resulting from risk situations. This implies broadening the focus of analysis that underpins the perception of risk in order to develop the possibility for students to produce assessments of limited or extended scope. In view of this, it is essential to reinforce the idea that risks, especially those resulting from reflexive modernity, need to be explicitly debated and rationalized, since they come incorporated from epistemological, psychological, sociological, cultural and pedagogical perspectives. And there is no more appropriate environment for this than schools. Students should be educated to recognize the risks generated by technoscience in order to be able to make well-informed decisions. We believe that the above requires a broadening of the concept of science education, especially in the development of an educational

project that is coherent with today's society and closer to contemporary problems.

Overcoming the deterministic illusion (Levrini, Pietrocola and Erduran, 2024) is a crucial intellectual and cultural step towards adapting scientific rationality and citizen education to the challenges of the risk society. It is about recognizing that complexity, contingency and uncertainty are not flaws to be eliminated, but intrinsic characteristics of the world in which we live and operate.

In this new context, the function of scientific rationality shifts. Its role ceases to be the ideal of "prediction and mastery" and becomes the "construction of provisional, revisable and socially robust guidelines". This change does not weaken science; on the contrary, it adapts it to a scenario of irreducible uncertainties and high-risk decisions. It is in this scenario that the notions of post-normal science and expanded deliberation take center stage, paving the way for a science that is better suited to contemporary challenges.

The implications of this reorientation for science education are direct and profound, outlining a new mission for science teaching in the 21st century. Citizen education must now include an expanded set of skills and dispositions:

Develop traditional conceptual skills, which remain the basis of scientific knowledge.

To train people to deal with uncertainty in a productive way, understanding it not as a deficit but as a condition for responsible action.

To enable citizens to make explicit the values that inevitably underlie techno-scientific decisions, overcoming false technical neutrality.

Promoting the ability to deliberate collectively on risks and possible futures, strengthening democratic participation in complex issues.

In short, science education for a risk society must go far beyond exercising knowledge to solve typical deterministic problems. Its new and more urgent task is to prepare citizens to participate critically, reflectively and responsibly in building a world where the future is not given, but needs to be continuously and collectively negotiated in the midst of uncertainty.

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