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Elements of Risk, Complexity, and Environmental Education in Science Teacher Education

Elementos do Risco, da Complexidade e da Educação Ambiental nas Formações em Ciências da Natureza

Elementos del Riesgo, la Complejidad y la Educación Ambiental en la Formación Científica

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Abstract

Contemporary realities, often marked by risk and uncertainty, particularly regarding environmental issues, have increasingly become matters of concern within schools. Seeking to understand how science education can meaningfully engage with such contexts, researchers from Grupo de Ensino de Ciências e suas Complexidades, Núcleo de Pesquisas em Inovações Curriculares, Equipe de Educação em Física Susana Leher de Souza Barros and Grupo de Pesquisa Educação em Ciências e Educação Ambiental have been developing studies that explore the interconnections between risk, complexity, and environmental education. This article examines the intersections and distinctive perspectives that emerge from these research groups, identifying the key elements that contribute to an educational approach capable of addressing the dynamic and complex challenges of the contemporary world. Methodologically, the study draws on the proposals and actions of these groups, organized within a structured network, and employs Content Analysis procedures. The findings suggest that science education should foster reflection on risk and uncertainty, the boomerang effect, the global–local relationship, critical and dialogical thinking, as well as incorporate elements of interdisciplinarity and Freirean principles inspired by the Thematic Approach.

Keywords: risk, complexity, environmental education, science teaching

Resumo

Assuntos que a realidade nos impõe, como aqueles permeados pelo risco e pelas incertezas, especialmente voltadas à questão ambiental, são preocupações também recorrentes na escola. Uma educação em ciências potencialmente capaz de lidar com essa realidade vem sendo estudada pelo Grupo de Ensino de Ciências e suas Complexidades, Núcleo de Pesquisas em Inovações Curriculares, Equipe de Educação em Física Susana Leher de Souza Barros e Grupo de Pesquisa Educação em Ciências e Educação Ambiental. Esses grupos de pesquisa promovem reflexões que abordam temas como o risco, a complexidade e a educação ambiental. Diante disso, este artigo investiga as aproximações e singularidades entre as abordagens desses investigadores, identificando os principais elementos que contribuem para uma formação capaz de lidar com a realidade dinâmica e complexa do mundo contemporâneo. Metodologicamente, os dados se referem às propostas e ações dos grupos, que foram organizadas em uma rede estruturada, e a análise baseia-se nos procedimentos da Análise de Conteúdo. Dos resultados, os grupos compartilham o entendimento de que a formação em ciências deve comportar uma reflexão sobre os riscos, as incertezas, o efeito bumerangue, a relação global-local, a criticidade, a dialogicidade e considerar elementos da interdisciplinaridade e da perspectiva freireana da Abordagem Temática.

Palavras-chave: risco, complexidade, educação ambiental, ensino de ciências

Resumen

Las realidades contemporáneas marcadas por el riesgo y la incertidumbre, especialmente en lo que respecta a las cuestiones ambientales, se han convertido en temas de creciente preocupación en el ámbito escolar. Con el objetivo de comprender cómo la educación científica puede responder de manera significativa a estos contextos, los grupos de investigación Grupo de Ensino de Ciências e suas Complexidades, del Núcleo de Pesquisas em Inovações Curriculares, de la Equipe de Educação em Física Susana Leher de Souza Barros y del Grupo de Pesquisa Educação em Ciências e Educação Ambiental vienen desarrollando estudios que exploran las relaciones entre riesgo, complejidad y educación ambiental. Este artículo analiza los puntos de convergencia y las particularidades que emergen de las perspectivas de estos grupos, identificando los principales elementos que contribuyen a una formación capaz de afrontar los desafíos dinámicos y complejos del mundo contemporáneo. Metodológicamente, el estudio se basa en las propuestas y acciones de los grupos, organizadas en una red estructurada, y utiliza procedimientos de Análisis de Contenido. Los resultados indican que la educación científica debe promover la reflexión sobre el riesgo y la incertidumbre, el efecto boomerang, la relación global-local, el pensamiento crítico y dialógico, e integrar elementos de la interdisciplinariedad y los principios freireanos del Enfoque Temático.

Palabras clave: riesgo, complejidad, educación ambiental, enseñanza de las ciencias

Introduction

Risks and uncertainties are present in our reality and are essential elements for addressing environmental issues. In other words, to address environmental issues, one must consider open and dynamic systems (Leff, 2010; Prigogine, 1996). These factors, often unpredictable and invisible (Beck, 2010), comprise the range of concerns of our society. Thus, the school faces another challenge: How to address contemporary environmental issues (open and dynamic) in this space and, at the same time, educate individuals capable of taking a stand on this reality. This is a question without a single answer because there are different ways to approach it, for example, focusing on students' positioning based on an already established idea such as planting trees, recycling materials, etc.

In the search for answers, we believe that the elements of complexity (Morin, 2007, 2020; Mitchell, 2009; Watanabe, 2012) and risk (Beck, 2010), and concerns about Environmental Education (EE) (Layrargues & Lima, 2014; García, 2004) can contribute to a more contextualized science education that keeps pace with current societal changes. In this article, we aim to investigate how research groups have been proposing to establish the relationships between these elements and science education based on theoretical aspects and parameters. Among them, the following stand out: *Grupo de Ensino de Ciências e suas Complexidades (GrECC), Núcleo de Pesquisas em Inovações Curriculares* (NUPIC), *Equipe de Educação em Física "Susana Leher de Souza Barros"* (EduFis), and *Grupo de Pesquisa Educação em Ciências e Educação Ambiental* (GPECEA), which, in their different approaches, articulate the construction of science teaching committed to

contemporary challenges. In accordance with project No. 2024/03921-4 of *Fundação de Amparo à Pesquisa do Estado de São Paulo* (FAPESP), groups from the state of São Paulo and one from Minas Gerais were selected. They present a significant scientific production on the elements of Risk, Complexity, and Environmental Education in the theoretical-methodological propositions that offer advances for thinking about and producing science teaching today.

From this perspective, considering the documents that guide Brazilian education, environmental education is addressed in the *Base Nacional Comum Curricular* (BNCC) (Ministry of Education, 2017), the national common curriculum base, focusing on the interaction between the individual and the environment and emphasizing the need to address socio-environmental issues in a cross-cutting and integrative manner. Furthermore, Law No. 9,795 (National Environmental Education Policy) highlights the need to implement EE in schools, aiming to strengthen critical awareness of socio-environmental problems and encouraging individual and collective actions in environmental preservation. It also emphasizes the need to incorporate EE, interdisciplinarily, at all levels of the educational process (Law No. 9.795, 1999). Subsequent amendments (Law No. 14,926, 2024) highlighted climate change, biodiversity protection, and risks and vulnerabilities (Ministry of Education, 2024). The theme of risk appears in the BNCC at specific moments, for example, in High School when suggesting working on skills and abilities that help students identify potential risks when seeking information in different technological media (Ministry of Education, 2017, p. 474); and in the specific skills of natural sciences when mentioning the assessment of potential risks to health and the environment, in topics such as radiation, toxicity and reactivity of materials and products (EM13CNT103 and EM13CNT104)[1] (Ministry of Education, 2017, p. 555). Finally, the BNCC approaches aspects of complexity when deal with the commitment to integral education and student development, indicating "understanding the complexity and non-linearity of this development, breaking with reductionist views" (Ministry of Education, 2017, p. 14); and when indicates in the curricular components the encouragement of research processes and practices the intensification of dialogue between reality, analyses and interventions considering broader and, consequently, more complex contexts (Ministry of Education, 2017, p. 551).

Considering the studies referenced in Environmental Education, García (2004) emphasizes the importance of promoting educational processes that favor the complexification of knowledge, understanding EE as a space for open reflection, capable of articulating uncertainties and different types of knowledge. Layrargues and Lima (2014) highlight the need to recognize the multidimensional nature of EE,

1 Alphanumeric code that identifies skill, area or curricular component, and competence, defined in the BNCC. The skills are: a) EM13CNT103 - Use knowledge about radiation and its origins to assess the potential and risks of its application in everyday equipment, in health, in the environment, in industry, in agriculture and in the generation of electricity; b) EM13CNT104 - Evaluate the benefits and risks to health and the environment, considering the composition, toxicity and reactivity of different materials and products, as well as the level of exposure to them, taking a critical position and proposing individual and/or collective solutions for their responsible use and disposal. (Ministry of Education, 2017, p. 555).

which articulates society, the individual, and education. Contributing to the dialogue, Calegari et al. (2025) address EE related to biodiversity, considering the importance of addressing environmental issues both globally and locally, an aspect that converges with the perspective of complexity. Fernandes and Parolin (2023) discuss transdisciplinary education and consider EE as possessing a complex and counter-reductionist way of thinking to address contemporary social and environmental issues. The works of GPECEA, such as that carried out by Pereira et al. (2021), seek to relate complexity, environmental education and science teaching, considering the perspective of complexity as a tool to improve and promote reflections on methodologies and pedagogical practices in these areas.

Considering the studies referenced on risk, Beck (2010) and Beck et al. (1997) discuss the conception of industrial society and the concept of reflexive modernization, addressing risks and their origins, perceptions, and possible consequences for current lifestyles. Some works of NUPIC also address risk, such as that of Pietrocola, Schnorr, and Rodrigues (2025), which seek strategies to address elements of risk society theory and manufactured risks in science education. For Pietrocola and Souza (2019), the construction of these strategies is necessary, since curricula do not incorporate, or produce little of, the discussion about risk society and its manufactured risks. The works of EduFis, specifically that of Silva et al. (2023), list, based on a collection of textbooks from the National Textbook Program (PNLD) of 2020–2024, the presence of the risk approach in themes related to water and water resources in the works.

Considering studies referenced from a complexity perspective, Morin (2007) defends the concept of complex thinking, promoting a paradigm shift that confronts the fragmentation of knowledge and the simplistic view of the world, seeking to promote a systemic and interconnected view of reality. Alves and Bego (2020) indirectly engage with the complexity perspective by considering, among the results of a systematic review, Morin's ideas in works on teaching and learning strategies. The GrECC defends complexity, arguing that it is essential to consider it across different dimensions. For example, Carvalho et al. (2022, p. 169) argue that "the development of open, dynamic, and integrated knowledge enables the formation of a citizen capable of becoming conscious and responsible, creating their own knowledge of the world". They also indicate a more complex education based on environmental themes, for example, when addressing Physics content through the issue of climate change (Carvalho & Watanabe, 2025).

Given these elements—complexity, risk, and environmental education—and considering the research groups that study them to reflect on the formation of subjects for contemporary society, the objective of this article is to investigate the similarities and differences between the approaches of GrECC, GPECEA, NUPIC, and EduFis, identifying the main elements that contribute to the formation of individuals capable of dealing with reality. Such formation implies proposing school actions and/or deepening epistemological perspectives.

Theoretical Framework

Elements of Environmental Education

Historically, environmental education (EE) can be understood as a plural field in constant re-signification, influenced by social, cultural, and political transformations and in response to the contemporary socio-environmental crisis. Layrargues and Lima (2014) investigate the field of EE in Brazil using frameworks that address Political Ecology and Bourdieu's notion of Social Field; they argue that EE is not a homogeneous universe, but rather a space addressed by different agents with distinct conceptions and interests. To better understand this diversity, the authors identify three macro-trends that are organized in a spectrum ranging from more conservative proposals, centered on individual and sectoral changes, to transformative perspectives, oriented towards structural and political changes. In this sense, they describe three currents of thought that guide the practices and discussions on EE in Brazil: the *conservationist* macro-trend, focused on an educational practice that seeks to awaken a new sensitivity towards nature, under the logic of "knowing to love, loving to preserve" (p. 27) and which emphasizes the "valorization of the affective dimension in relation to nature" (p. 30); the *pragmatic* approach, focused on waste management and sustainable consumption, overcoming the individualistic vision but which is geared towards market trends and interests; and the *critical* perspective, which defends a transformative stance and seeks to "contextualize and politicize the environmental debate" (p. 33). In current social contexts, it becomes fundamental to think about environmental education from a critical perspective, that is, beyond fragmented and reductionist approaches, recognizing it as a practice that articulates multiple forms of knowledge, promotes the problematization of reality, and stimulates the construction of fairer and more sustainable social and environmental alternatives. As the authors state, "the magnitude of the challenges and uncertainties we experience in high modernity does not allow for reductions; on the contrary, it demands openness, inclusion, dialogue, and the ability to see the new and to formulate responses beyond the known" (Layrargues & Lima, 2014, p. 33, our translation). In convergence with these ideas, Rodríguez and García (2009) discuss how the EE models (naturalist, conservationist, and technocratic) are articulated in the teaching and learning process. They also present integrative EE, which advocates for the formation of conscious, critical citizens capable of acting responsibly towards the environment and stands out as a more comprehensive and complex model.

Bringing the discussions closer to the school context, García (2004) argues that school is a possible space for promoting open reflections that consider the dynamism and complexity of relationships. He discusses an environmental education that goes beyond the fragmented and reductionist vision, recognizing the interdependence between society, nature, and culture. For the author, such a perspective implies fostering educational processes that favor critical thinking, the problematization of lifestyles, and the collective construction of alternatives that engage with uncertainty, the diversity of

knowledge, and contemporary challenges. To this end, the idea of the complexification of thought (Garcia, 2004) is reinforced by discussions of scientific, school, and everyday knowledge. In convergence with these ideas, Leff (2010, 2011) defends the application of an environmental pedagogy, based on environmental interdisciplinarity and environmental complexity, which aims to bring together and hybridize knowledge considered marginalized with scientific knowledge to combat the environmental crisis generated by reductionism.

In dialogue with these reflections, Watanabe and Kawamura (2014) highlight Critical, Complex, and Reflective Environmental Education ($_{CCR}$EE), which considers the interconnections between the different dimensions of environmental problems and the influence of social, political, and economic factors, for example. They question the traditional view of science education, which is insufficient to deal with the complexity of socio-environmental problems. Furthermore, by understanding that the dynamics of societies are increasingly complex, with global environmental crises and urgent social challenges, $_{CCR}$EE contributes to the formation of individuals capable of understanding the complexity of these problems, such as power relations and social inequalities.

An environmental education grounded in complexity must also consider the risks present in society, recognizing that individuals' positions need to be constructed from a different perspective. In this sense, EE ceases to be treated in isolation and begins to integrate socio-political, socio-cultural, and historical processes, becoming intrinsic to the real world, including in contexts marked by struggles for survival. To adopt this perspective means to incorporate conceptual and social parameters that encourage reflection and offer students the conditions to develop ways of dealing with the uncertainties of the present. Watanabe and Kawamura (2014) argue that this requires a change in thinking, guided by precepts of complexity that involve an anti-reductionist stance, capable of identifying simplifying discourses and confronting paradoxes and contradictions inherent in contemporary times.

Elements of Complexity

To address environmental issues in education, it is necessary to adopt a scientific perspective that encompasses uncertainties, risks, and the awareness that such issues are open-ended and complex. We can distinguish three perspectives on science: the deterministic, the indeterministic, and the complexity-based perspectives (Cini, 1994). The deterministic perspective is defined by Watanabe (2012) as one that brings predictability, confidence, and certainty with true and unique answers by isolating the object analyzed, generating simplification of the system. The indeterministic perspective is defined by Watanabe (2012, p. 102) as one that allows us to find answers even when the object being analyzed is not fully known; that is, it focuses on the relationships within the system, based on the imposition of theoretical reasons, such as Heisenberg's uncertainty principle. Finally, the complexity perspective allows us to analyze relationships in the natural world where situations are dynamic and out of equilibrium, presenting chaos

and disorder, ceasing to isolate the objects of study and excluding the possibility of analyzing a system in its totality. Watanabe (2012, p. 103) argues that it seeks, with scientific content, to bring reflections that approximate reality to *uncertainties*. Among them, the complex perspective seems ideal for addressing environmental issues, since it considers the reality. Thinking about this, Mitchell (2009) defines this perspective through the vision of systems, which are self-organized and composed in a simple way, interacting with each other without depending on central control, causing dynamic and unpredictable patterns. Morin (2007) addresses complexity through the interconnection of information, enabling complete knowledge, without reaching totality.

In this sense, Mitchell (2009) presents a more systematized view of complexity, showing common characteristics present in the systems, namely: collective behavior (the parts interact to generate complex patterns), information processing (the ability to collect, store, and use data), and adaptation (the ability to change in response to a changing environment). In this context, Mitchell (2009) discusses dynamic systems and shows one of their main characteristics: sensitivity dependent on initial conditions, which characterizes the constant and unpredictable changes in these systems, in addition to making prediction challenging and generating uncertainty. However, the bifurcation path from period to chaos present in systems allows us to verify a certain order, generating coexistence between order and disorder. It is important to emphasize that the presence of entropy in complex systems is fundamental to understanding the chaotic behavior of states of order and disorder, but to behave appropriately, information is a key element, since it allows communication between the parts of the system. Thus, Mitchell (2009) uses computing and biology to mimic nature on computers and to identify computational characteristics in the environment. In this process, she presents us with the prisoner's dilemma, which stimulated the study, through computational simulation, of how society functions. Through her analyses, the author shows us that for a society to be functional and cooperative, the population must have indulgent, retaliatory, and clear behavior.

According to Morin (2007), the perspective of complexity proposes a *paradigm shift* as a key point, encouraging the abandonment of deterministic views in favor of a comprehensive and interconnected understanding of reality. With this in mind, he proposes *complex thinking*, which aims to organize knowledge to overcome the fragmentation generated by determinism, offering tools to deal with contemporary issues. Another key point raised by the author concerns the behavior of complex systems, such as self-organization, in which order and disorder coexist within the system, such that disorder contributes to the restoration of order; and self-eco-organization, in which order and disorder coexist, but the environment acts as a co-author. In this sense, considering *local and global aspects*, the author presents the principle of organizational recursion, in which everything that is generated returns to the generator, producing a self-organizing cycle, such as society (global), which is impacted by individual action (local). Furthermore, Morin (2020) emphasizes that, due to self-organization, uncertainty is

present from the perspective of complexity, generating a "festival of uncertainties" in systems, such as society. For Morin (2007), the development of *complex thought* involves transdisciplinarity, which seeks to integrate areas of knowledge, but without removing their identities. For him, these factors, together with the subject-world interaction, have a great influence on the formation of subjects, being a path to achieving complex thought.

Elements of Risk

According to Beck (2010), the Risk Society can be understood as a stage in which the risks and threats generated by the system itself outweigh the wealth and benefits produced. Unlike the dangers of the past, associated with a predominantly local perspective, the new risks can be interpreted as "side effects" of modernization, science, and technology; and they also have a global character. Risk affects all social classes, being produced by technological development and human action, as well as being predictable and a product of society itself (Giddens, 1991). As they are unequally distributed, they affect the poorest layers of society more intensely, as Beck (2010, p. 40, our translation) states when commenting that "the possibilities and capacities to deal with risk situations, to circumvent or compensate for them, end up being unequally distributed among different income and education levels".

In this scenario, the risks of modernization are a "serial product of the industrial machinery of progress, systematically aggravated by its further development" (Beck, 2010, p. 26, our translation). They create future actions/events and produce the constitution of danger, since "[...] it exists in circumstances of risk and is in fact relevant to the definition of what risk is" (Giddens, 1991, p. 34, our translation), and individuals may or may not be aware of this relationship when considering "calculated risks" or the unconsciousness of risky actions (Giddens, 1991, p. 36). Awareness of risks can trigger preventive actions in the space where threats occur, since risk can generate the perception of a potential catastrophe, enabling management through choices and attempts at preventive actions, without disregarding the historically determined context that produced them (Veyret, 2007).

In this context, scientific and technological development reveals itself to be ambivalent, since on the one hand it generates new risks, and on the other, it provides instruments for their mitigation. This ambivalence (generating risks and providing solutions) inserts society into a cycle of reflexivity, in which the consequences of its own advances are continually questioned and decision-making and management processes are reevaluated. It is in this sense that Beck (2010) and Beck, Giddens, and Lash (1997) expand the discussion and present the concept of reflexive modernity, understood as the process by which industrial society is forced to confront the consequences and risks that it produces, since it is understood that the problems and risks are reflections of the very progress resulting from this society. This is a form of "creative (self)destruction" (Beck et al., 1997, p. 12) not resulting from an external crisis, but from the very development of modernization. This transformation radicalizes modernity by permeating the contours

of industrial society, paving the way for "another modernity", sustained by new premises and social relations. Reflexivity, in this context, is configured as an inevitable self-confrontation, a moment in which "society becomes a theme and a problem for itself" (Beck; Giddens; Lash, 1997, p. 19, our translation), being forced to question its social, political, and economic foundations. Thus, "social practices are constantly examined and reformed in the light of renewed information about these very practices" (Giddens, 1991, p. 39, our translation). This includes, according to Giddens (1991), reflection on the nature of reflection itself, as well as the understanding that knowledge partially constitutes the forms of social life, in which social practices are altered by the revision of the conventions that encompass aspects of human life, including the impact of technological advancement, through new information and knowledge.

A central aspect of this debate is the boomerang effect, which highlights the almost inevitable return of risks to those who produced them or profited from them. Due to the unpredictability and global nature of threats, risks do not respect borders, returning directly or indirectly. Regarding this concept, Beck (2010) points out that

> (...) the boomerang effect does not need to be reflected, therefore, solely in a direct threat to life, but can also occur through mediations: money, property, legitimation. It does not only directly affect the isolated perpetrator. It also makes everyone, globally and equally, bear the burden (Beck, 2010, p. 45, our translation).

Thus, the effect occurs through the uncontrolled production of risks from modernization and, in a generalized way, promotes not only the threat to life, but also threatens "the property and commercial interests of those who live off the commodification of life and food" (Beck, 2010, p. 46, our translation), thus configuring itself as a contradiction between the interests of profit and property and the threatening consequences that generate them.

Discussions about risk, therefore, point to the need to understand it from other dimensions. Approaching the realm of science education, these are fundamental ideas for the formation of individuals capable of positioning themselves in the face of current dilemmas and challenges, so that they can establish a more dialogical and engaged relationship with science and technology based on themes and contexts related to risk in reflexive modernity and the consequences of modernity (Pietrocola & Souza, 2019). Thus, global, invisible, and unpredictable risks reinforce the need to rethink school education, paving the way for another way of thinking, more critical, dialogical, and sensitive to complexity, building pathways to formulate a risk awareness (Pietrocola & Souza, 2019).

Methodological Aspects

This is a theoretical-empirical study of a qualitative nature (Bogdan & Biklen, 1994; Lüdke & André, 1986), which uses Content Analysis (Bardin, 2016) for data interpretation and categorization. Data collection involved observing the group members (identified as researchers *P1, P2, …, Px*) during meetings, both with the complete team and with specific teams. These meetings were part of the research project[2] "*A perspectiva da complexidade para abordar questões socioambientais e riscos*", funded by the *Fundação de Amparo à Pesquisa do Estado de São Paulo* (FAPESP). It is worth noting that the choice of the investigated groups was based on the connection between the themes of complexity, risk, and environmental education, highlighting a complex and rich field of investigation. The criteria for their selection were based on three lines of research, delimited from elements of complexity and related theoretical frameworks, namely: (Line 1, to which Group 1 belongs) Dimensions of complexity and perspectives of science; (Line 2, to which Groups 2 and 3 belong) Risks and uncertainties of the world; and (Line 3, to which Group 4 belongs) Formative perspective of environmental education. The groups refer to:

- *Grupo de Ensino de Ciências e suas Complexidades* (GrECC) - proposes school actions that promote a Freirean critical education, based on elements that articulate aspects of complexity and environment, in addition to encompassing studies related to education for risk, personal methodological models, levels of formulations, and transition hypotheses.
- *Núcleo de Pesquisas em Inovações Curriculares* (NUPIC) - proposes the development of teaching materials, initial and continuing teacher training, curricular proposals, and knowledge related to teaching and learning processes in schools, based on risk education, innovations in Modern Physics content, and public health issues.
- *Equipe de Educação em Física "Susana Leher de Souza Barros"* (EduFis) - with a central focus on teacher training, investigates the factors that influence and the aspects that condition the inclusion of risk education in science education, based on the theory of risk society and a critical training to work on their research.
- *Grupo de Pesquisa Educação em Ciências e Educação Ambiental* (GPECEA) - works to understand the different perspectives and theoretical and methodological articulations between the fields of science education and environmental education. They base their work on STS/STSE and cultural issues to analyze conceptions and discursive practices on socio-environmental issues and science education.

2 This work is part of the project "*A perspectiva da complexidade para abordar questões socioambientais e riscos*", funded by the FAPESP under process No. 2024/03921-4. Plataforma Brasil (CAAE: 69067823.1.0000.5594)

The three stages that comprise the research are: (i) data collection in five online meetings with the entire project team; (ii) data collection in one online meeting with specific groups; and (iii) systematization of data and results. In (i) and (ii), the data collected occurred through conversations during the meetings, which were organized in the Teacher's Diary (Porlán & Martín, 1997) and semi-structured interviews (Triviños, 1987; Manzini, 2012), guided by the following questions:

- (GrECC) (A) *What characteristics of scientific perspectives are necessary to deal with contemporary knowledge?* (B) *What characterizes a contemporary subject formed from the precepts of complex thought? What characterizes a subject considering training for contemporary science?*
- (EduFis and NUPIC) (A) *What characterizes the risks experienced in the 21st century?* (B) *How can individuals, especially teachers, be trained to implement teaching and learning situations that address risk-trust and involve risk situations and their characteristic uncertainties?*
- (GPECEA) (A) *What characterizes environmental education today?* (B) *What aspects of environmental education contribute to shaping a contemporary individual?*

It is noted that the guiding questions (A) and (B) were developed for each group considering their specificities, announced by the researchers themselves and linked to their lines of research. Question (A) is concerned with the worldview and (B) with the subject's formation to act in this world. Furthermore, the questions for EduFis and NUPIC are the same, given the more central interest in risk. The data in the Teacher's Diary were organized in a table with the groups' responses based on the guiding questions (A) and (B). During the meetings of stage (i), the authors noted the responses of the group members indicating their references, work, and ideas about the theme of complexity, risk, and Environmental Education. In stage (ii), the group coordinators reviewed this material for supplementation and clarification. Specifically in (ii), the meeting lasted about an hour, consisting of reference statements made by the affiliated researchers. In short, these speeches concerned their main theoretical frameworks, their lines of work, the research and outreach activities that were being or had been developed up to the time of the meeting, as well as the presentation of the team.

In stage (iii), the data obtained in (i) and (ii) were systematized into a network, produced using the *Obsidian* application, version 1.9.14. For this systematization, that is, to identify the relationship between complexity, knowledge, and epistemology for each of the groups, Content Analysis (Bardin, 2016) was carried out, that is, a set of techniques aimed at the systematic and objective description of the content of the communications. In this process, we followed the steps of identifying the characteristics and formulating the key elements to understand the relationships, a general reading of the data presented in the Teacher's Diary, constructed during stages (i) and (ii), and subsequently, the fragmentation of the contents into recording units, building a broad interpretation of the categories presented below.

Results and Discussion

This section is organized into two analytical moments, in which the singularities and similarities between the research groups are systematized, considering the theoretical parameters that mobilize them, namely: complexity, risk, and EE.

The Singularities of Each Group

The singularities represent what each group identifies as intentionalities of formation, with little or no connection to the other groups, identified during the meetings of stages (i) and (ii). It is worth noting that the groups may present specific concepts that, although they dialogue with risk, complexity, and EE, they are not explored in depth.

In the GrECC, the main theoretical references correspond to Morin, Prigogine, Freire, Beck, and García. In this sense, the concepts that underpin their actions are evident in the researchers' answers to the guiding question (A). Thus, *dimensions of complexity, emphases on complexity, and critical, complex, and reflective environmental education* ($_{CCR}$EE) are GrECC propositions based on these authors. The dimensions refer to spaces in which the perspective of complexity can be worked on to promote critical and reflective education. They are: *educational dimension* (identification of parameters and formative perspectives in complexity to form reflective subjects, with complex thinking and capable of *complexifying* knowledge, that is, what is expected of the student during class beyond the content); *teaching-learning dimension* (refers to what the teacher can work with to promote the perspective of complexity in school, that is, practices, tools, and methods adopted to achieve the objectives in the classroom); and *epistemological dimension* (identification of scientific and school approaches that allow working with the perspective of complexity, that is, epistemological approach) (Watanabe, 2021; 2012). *Emphases*, on the other hand, are means of articulating these spaces with school activities, namely: dynamic, temporal, entropic and interrelational emphases (Watanabe, 2025). They carry elements of life, time, and development, in which entropy varies according to human action and causes irreversibility (Watanabe & Kawamura, 2020). They define that "life should be seen as a system part of complexity; time should consider the unpredictability and irreversibility of the passage of time, considering the history of the environment, culture and historical concepts, including them in the complex system; and the development is based on evolutionary processes of systems, in which nature, historical contexts, and intentions influence their finitude, limit development, and bring sustainability through complexity" (*P5*, excerpt from Teacher's Diary, 2025, p. 1). Meanwhile, the $_{CCR}$EE (Watanabe & Kawamura, 2014) indicates elements for a socio-environmental education that incorporates critical, complex, and reflective elements, contributing to the formation of individuals prepared to live in a world permeated by risks and uncertainties, encouraging a critical stance towards scientific and social knowledge. Furthermore, it promotes active and conscious participation in the search for socio-environmental solutions, so that individuals understand the environment as a dynamic system in transformation, where new conditions and elements can constantly emerge.

Considering question (B), the group indicates *systems* and *chance*, *chaos* and *disorder*, based on the precepts defended by Prigogine (1996) when discussing uncertainties and risks in natural systems in non-equilibrium Physics. When discussing these aspects, they point to the emphases of complexity, especially highlighting the dynamic and entropic emphases that bring at their core, respectively, the idea of considering the unpredictability and uncertainties of the Earth system when dealing with the movements and possible trajectories involved in the processes; and explaining the impossibility of making the system return to its initial state. Thus, it is highlighted that its organization only occurs at the cost of increasing global entropy, dissipating energy to self-organize, and reconsidering the 1st and 2nd Laws of Thermodynamics (Watanabe, 2025). Furthermore, they advocate for Morin's approach to *complex thought*, which, instead of separating, relating, and uniting, seeks construction and deconstruction based on uncertainties and ruptures (Carvalho et al., 2022; Carvalho & Watanabe, 2025). These ideas are observed, for example, in the speech of *P1* (excerpt from Teacher's Diary, 2025, p. 3) when highlighting the formation of a subject "that, guided by the paradigm shift considering complexity, is capable of dealing with the uncertainties of the contemporary world and understanding the worldview from different points of view/perspectives".

NUPIC works with research related to the development, application, and analysis of teaching-learning proposals for science education. Its main theoretical references are Beck, Giddens, and Lipovetsky. They focus on risk as a primary theme, articulating it with issues of sustainability, *public health, disruptive technologies*, the virtual world, scientific investigation in schools, and human rights. For question (A), initially, they indicate the factors considered by Beck (2010), such as *reflexivity*, manufactured risks, and expert systems to understand the separation between fact and risk perception—that risks arise from society and to work with the idea of the end of nature and tradition. In this sense, they emphasize the factor of uncertainty and the use of science to deal with issues of time such as past, present, and future. They mention that the determination of the present is lost and we live in a moment of risk where there is only the present. By citing Giddens (2002), they highlight that modernity interprets the past, so that we do not actually have a past, generating a breakdown in the interpretation of the future. They argue that we are in a perpetual present (since there is no past or future), in which there is chaos and uncertainty. By citing Lipovetsky (2011), they address progress beyond scientific overachievement. Furthermore, they emphasize the importance of working with *trust* in this context, since for Giddens (2002) it becomes a central factor in the social context of late modernity and is questioned by the presence of risk and uncertainty in the context of *ontological security*. These ideas are observed, for example, in the speech of P2 (excerpt from the Teacher's Diary, 2025, p. 2) when raising questions about the type of scientific epistemology necessary to understand the notion of time, stating that "there are uncertainties (and impotence) about the future".

Considering (B), NUPIC understands that the subject is immersed in and is a product of a risk society, just as it has uncertainties about the future. Furthermore, they consider the subject to be both *scientific and socially formative agent*. In this sense, they revisit the concept of trust and argue that it should be worked on within the school, and for this, it is necessary to address it also in teacher training, so that teachers can bring these issues into the formation of subjects in the school. In other words, the group seeks to train teachers to understand and work with the presence of risk and trust through pedagogical situations and teaching and learning strategies, considering the production of a *modern, reflective science education* that seeks to contribute to the construction of risk awareness through a dialogical and reflective relationship regarding science and technology issues (Zambrano-González & Pietrocola, 2025; Pietrocola & Souza, 2019).

EduFis investigates the factors that influence and condition the incorporation of risk education into science education, presenting Beck and Veyret (who proposes discussions on manufactured risks and their implications in current society and education) as its main theoretical references. For question (A), which refers to the characterization of risks experienced in the 21st century, the group understands that *risk in technology* constitutes contemporary risks, being phenomena that break and transcend time and space, characterized by the unpredictability of their consequences. Thus, modern risks are produced and intensified by human action, as they are articulated with the advancement of scientific production and knowledge. Therefore, they argue that risks are not interpreted and experienced in the same way, encompassing the notion of context discussed by Veyret (2007), emphasizing the existence of a subjective and political dimension that impacts societies in different ways. From this perspective, even considering the boomerang effect (Beck, 2010) of risks, the way they are experienced by the most vulnerable societies differs from the other end of the capitalist system, where, from a capitalist logic, situations arising from risks can generate new opportunities for the market, highlighting the *risk of progress*. Therefore, the group recognizes the need to *build instruments to deal with risks*, understanding this movement as a role of current science. And to face situations that generate risks, it is necessary to recognize the situations that can cause risks, their possible impacts, and the recognition that crises promoted by the realization of risks today generate global interdependence, considering that the impacts are not only on local scales.

Considering question (B), which deals with the formation of individuals, the aim is to find ways to work in teaching-learning situations. This search seeks to encompass a *critical education* capable of involving society in dealing with contemporary problems, situations, and challenges that affect not only the present moment but also impact an idea of the future. Therefore, risk education should not only be about *prevention* but should also encompass reflective and critical approaches to dealing with post-damage situations. Themes related to risk, as well as their study in basic education and teacher training, should emerge in connection with *risk in students' daily lives* and activities. Some activities from this group can be mentioned as a way to understand the theoretical-

practical action produced in risk education. One of them is the analysis of textbooks from the PNLD (the National Textbook Program), which revealed gaps in study objects, such as the theme of water resources as a risk (Silva et al., 2023). These ideas are observed, for example, in the speech of *P3* (excerpt from Teacher's Diary, 2025, p. 3) when highlighting the importance of a critical training of subjects, defending an "education for risk that promotes critical reflection and involves the whole society in facing risks".

GPECEA aims to support the development of work and research that problematizes discursive practices related to the relationship between science education and socio-environmental issues. The group is interested in understanding the possibilities and limitations of the educational process in the face of socio-environmental issues, valuing the dialogue of knowledge, environmental justice, and the appreciation of cultural contexts in the construction of knowledge, drawing on authors such as Leff, Layrargues, Morin, Prigogine, Stengers, Saito, Malm, and Freire. For question (A), the concern is to consider environmental education from a socio-political and *environmental justice* perspective, which implies recognizing its interfaces with Latin American *decolonial thought*, Freirean studies, and indigenous epistemologies, expanding the possibilities of understanding and acting in the face of environmental and epistemological inequalities. In this sense, it is understood from a critical and emancipatory perspective, influenced by Critical Theory (which questions the social structures that sustain environmental collapse). This approach connects with the dimension of *affectivity* and the construction of subjectivity, valuing the aesthetic relationship of natural environments. Thus, environmental education is understood as a discursive practice, approaching a complex perspective. In the context of science education, particularly Physics, questions arise about which elements of EE can be mobilized to qualify complex pedagogical practices and which tools teachers can use to incorporate Freirean perspectives into the classroom, promoting a critical, dialogical education committed to social and environmental transformation (Silva, 2025). Therefore, aspects of complexity guide the group, such as treating natural and social processes as open, dynamic, and interconnected systems, marked by uncertainty and the emergence of adaptation. In this sense, it aligns with an approach that recognizes instability and indeterminacy as constitutive elements of scientific and educational knowledge. Socio-environmental issues are treated as political and discursive constructions that demand the involvement of different knowledge and social actors, as well as historical and political influences. Regarding Science Education, the reflections point to a dialogical and critical approach, in which scientific knowledge is understood as a cultural construction, traversed by power relations, knowledge, and language, in addition to including aspects of *Science, Technology, Society and Environment* (STSE) Education. These ideas are observed, for example, in the speech of P4 (excerpt from Teacher's Diary, 2025, p. 2) when highlighting plural perspectives and questions about EE, evidencing the importance of "thinking about EE from a socio-political and environmental justice perspective (referencing the dialogue between Latin American decolonial thought, Freirean studies, and indigenous epistemologies)".

Considering question (B), they challenge conceptions that disregard the influence of contradictions, singularities, and contexts in the formation of individuals. The formation of a contemporary subject, therefore, implies thinking of them as a global and integral being, and not idealizing them as a fixed and normative model. In this sense, it is essential to understand them as part of a construction/formation that permeates multiple dimensions, political, affective, cultural, and historical, for example, and that they are capable of thinking, intervening, and transforming their reality. For the group, this understanding is aligned with the discussions proposed by theoretical frameworks such as Freire and Levinson, encompassing perspectives that address the *socio-political and eco-political* formation of individuals. Furthermore, they believe in the formation of subjects capable of acting in the transformation of realities through Critical Theory. In the post-critical context, this also implies considering the dimensions of sensitivity and *affectivity* in formative processes, recognizing that the connection with the world is not only rational, but also aesthetic and emotional. Another central aspect is considering the cultural data indicated by Clifford Geertz, understanding "the contemporary subject as both producer and product of *cultural issues*" (*P6*, excerpt from Teacher's Diary, 2025, p. 4). Environmental education, therefore, needs to engage with these issues, avoiding the risk of imposing a "correct" or "adequate" view of the world, as occurs in more traditional proposals, such as a normative EE centered on individual actions (Leite & Silva, 2021).

The Similarities between the Groups

By analyzing the similarities, it is noted that the concept of *risk* is unanimous among the groups in defending an education for contemporary times. Thus, it represents a key concept, along with the perspective of complexity, to propose an education capable of dealing with reality. Risk for GrECC is based on Beck's theory of risk society and the issues of reflexivity presented by Giddens (2002). For him, risk is an essential element to characterize the educational dimension of complexity, which in turn focuses on the formation of subjects who deal with risks and who are able to face the problems of the world using the precepts of complex thinking. This intentionality is reflected in the group's production, which portrays the concern with risk (Cuzziol, 2023) when investigating the similarities between aspects related to it from a theoretical point of view and in the perceptions of teachers in basic education in the public school system, focusing on the development of a proposal for science classes. For GPECEA, risk refers to a vision that encompasses social values and interests, especially political ones, involving environmental issues. For NUPIC, it involves incorporating issues from risk society theory, reflexivity, expert systems, and manufactured risks to support risk perception, risk awareness, and the training of individuals who understand their immersion and role as a product in a risk society. EduFis, supported by risk society theory, considers it important to highlight the subjectivity of modern risks, unpredictability, and their consequences on society, seeking to foster the development of individuals who reflect critically to deal with risks and work towards precaution.

The concept of the *boomerang effect* appears in GrECC, EduFis, and NUPIC, indicating a convergence in the understanding of risk as part of reflective processes, even if mobilized in different ways in different formative and theoretical contexts. In GrECC, it appears among the theoretical concepts that situate the educational dimension of complexity. For example, the work of Santos and Watanabe (2025) proposes a set of lessons that starts from the conception of a subject capable of recognizing themselves as an inseparable part of the environment, of understanding the interrelationships between natural and social phenomena, and of acting critically and responsibly, making decisions that consider the uncertainties and risks of the contemporary world. In EduFis, the boomerang effect is considered a conceptual basis, especially when defining it from a risk perspective: "risk ends up affecting the most vulnerable, but it can return to its generator (large companies and wealthier segments of society, for example). However, risk does not affect capitalism, so it transforms into market opportunities (capitalist logic)" (*P3*, excerpt from the Teacher's Diary, 2025, p. 1). Although NUPIC does not explicitly address the boomerang effect, it is understood that the group also considers it in the conceptual stage and as a fundamental part of its training actions. This is because, in the face of manufactured risks, risk awareness must involve understanding the contradiction of the production of these risks, as well as the impacts of expert systems. Therefore, the risks produced by modernity return to their own producers, making it necessary to incorporate the recognition of these risks and their interdependencies for the construction of a critical reflection on events.

Still within the context of risk, GrECC shares with NUPIC the element of *uncertainty*, indicating convergence regarding its presence in reality, although they use different authors to address it. GrECC deals with uncertainties mainly considering Prigogine's ideas when addressing open and dynamic questions. They present them as fundamental in both the educational and epistemological dimensions, and this, in turn, reflects in the temporal emphasis. This emphasis contemplates the temporal character of the Earth system, highlighting that it is conditioned by historical contingencies, so that current interferences in the environment can result in future changes, leading to new equilibrium situations that may (or may not) provide conditions for the maintenance of life on Earth. It also considers the impossibility of inferring precise results in a short period of time, for example, when working in non-equilibrium Physics with the concept of 'arrow of time', fluctuations and bifurcations; considering the uncertainties of the models (Watanabe, 2025). NUPIC addresses uncertainty by presenting discussions about the future and the present, starting from Laplace's demon paradox and Beck's determination of present time, and time from Giddens' perspective. Thus, they consider uncertainties about the future in the formation of individuals.

GrECC and GPECEA share elements of *thematic approach*, *criticality* and *dialogicity*, as well as *global and local aspects*, relating Freire's approach to the perspective of complexity. GPECEA highlights the importance of constructing pedagogical proposals based on the thematic approach, using problem situations and generating themes as a

foundation. They justify this by stating that it intensifies student engagement, adding meaning through interest and motivation, and promoting work on criticality and dialogicity. Furthermore, they perceive that the formation of the individual involves an interpretation of narratives, symbols, habits, and discourses circulating in societies (locally and globally), including technology and digital media. GrECC considers these elements in the application of a Critical Environmental Education by proposing "teaching that promotes scientific investigation along with critical awareness and social, cultural, and economic responsibility" (*P1*, excerpt from Teacher's Diary, 2025, p. 1), a concern present in the teaching-learning dimension of complexity and in the formation of individuals. They seek to consider global aspects, not just local ones, to recognize the impacts they cause on the environment, and propose actions based on the students' reality, such as the work that links the reading of the world through the rap song "Chuva Ácida" by Criolo (Roman, 2025).

EduFis and NUPIC share an *interdisciplinary* approach, arguing that it allows for working with risk and environmental issues, considering, for example, the boomerang effect. EduFis incorporates interdisciplinarity through actions that link risk to students' daily activities; projects such as the Institutional Scholarship Program for Teaching Initiation (PIBID); and the production of didactic sequences. They also advocate for the adoption of interdisciplinary dialogues to address the risks generated by global crises (*P7*, excerpt from Teacher's Diary, 2025, p. 1). NUPIC addresses this element primarily in the formation of individuals by working on how to deal with the notion of time and space, considering the context of risk (*P8*, excerpt from Teacher's Diary, 2025, p. 3).

As a synthesis of these results, Figure 1 presents the similarities and singularities between the groups. For its interpretation, it is important to consider that the gray points correspond to the similarities between the groups; the blue ones to the singularities of GrECC; the orange ones to the singularities of NUPIC; the green ones to the singularities of EduFis; and the yellow ones to the singularities of GPECEA.

Figure 1

Singularities and similarities of the main ideas on complexity, risk, and Environmental Education guiding the groups

Conclusions and Implications

In the search for epistemological perspectives, school actions, and the intention to educate individuals for contemporary times, the groups involved here presented common characteristics when seeking an education capable of dealing with reality. That is, with the intention of educating individuals from this perspective, they consider it fundamental to promote teaching and education that incorporate local and global aspects (issues/problems); that address risk, the boomerang effect, and uncertainty (whether present or future); and that are based on the elements of the Thematic Approach, criticality and dialogicity, and interdisciplinarity.

In a more unique way, for example, Group 1 pointed to aspects such as *dimensions of complexity, systems and chance, chaos and disorder*, and *complex thinking*, etc., as essential elements; and Group 4 pointed to *cultural issues, environmental justice, decolonial thought*, etc. These specificities show that an educational formation less rooted in a conceptual and traditional perspective also requires considering elements

that strengthen and communicate with other frameworks of reference and other ideas. In a certain sense, this is connected to the perspective of complexity, which is capable of dealing with both the parts and the whole.

More specifically, and focusing on the concepts that guided this study—complexity, risk, and environmental education—, this research indicates that the perspective of complexity presents elements such as promoting a paradigm shift through *complex thinking*, considering uncertainties, global and local aspects, and the interconnection between information and issues present in the contemporary world. Furthermore, addressing risk in this context allows us to develop diverse discussions and works on topics such as prevention, trust, and how to deal with the uncertainties and risks present in the globalized world. Also, by encouraging the articulation of different areas of knowledge, for example around complex socio-environmental issues, especially those related to the climate emergency, the possibility of overcoming technocratic and fragmented approaches is broadened. This integration favors the construction of broader and more contextualized meanings, allowing individuals to understand multiple dimensions of environmental issues and develop more consistent and committed stances and proposals for social transformation.

In the context of promoting a more critical environmental education, an approach that highlights the challenges of the contemporary world and encourages educational practices that go beyond reductionist and simplistic views can contribute to preparing individuals capable of understanding the unpredictability of the future, acting in the face of socio-environmental crises, and building alternatives towards more just and sustainable societies.

From a risk perspective, it is important to incorporate social, political, and subjective aspects that permeate environmental issues, making it an essential element in the educational dimension of complexity. Risk education goes beyond approaches focused solely on prevention, requiring the recognition of situations that produce risks, their impacts, and their global and interdependent dimension. In this sense, it contributes to the formation of individuals capable of dealing with the uncertainties of the contemporary world and understanding the production of risks, guided by complex thinking and risk awareness.

Finally, the implications of this work point to the need to develop formative pedagogical practices that incorporate the dimensions discussed throughout the text, in order to promote teaching and learning spaces in which individuals who recognize themselves as agents of transformation are formed. Furthermore, they reinforce the relevance of discussing teaching from the perspectives of complexity, risk, and integrative environmental education, so as to enhance processes that are contextualized and provide possibilities for a future in the face of uncertainty.

Authors' Contribution

Conceptualization: Laranjeira, H. F., Santos, C. S., Reis, A. C. A., Silva, L. F., Silva, L. L., Pietrocola, M., Watanabe, G.; **Data curation:** Laranjeira, H. F., Santos, C. S., Reis, A. C. A., Watanabe, G.; **Formal analysis:** Laranjeira, H. F., Santos, C. S., Reis, A. C. A., Watanabe, G.; **Funding acquisition:** Watanabe, G.; **Investigation:** Laranjeira, H. F., Santos, C. S., Reis, A. C. A., Watanabe, G.; **Methodology:** Laranjeira, H. F., Santos, C. S., Reis, A. C. A., Watanabe, G.; **Project administration:** Laranjeira, H. F., Reis, A. C. A., Watanabe, G.; **Resources:** Watanabe, G.; **Software:** Laranjeira, H. F.; **Supervision:** Laranjeira, H. F. , Watanabe, G.; **Validation:** Watanabe, G.; **Visualization:** Laranjeira, H. F., Santos, C. S., Reis, A. C. A., Silva, L. F., Silva, L. L., Pietrocola, M., Watanabe, G.; **Writing – original draft:**Laranjeira, H. F., Santos, C. S., Reis, A. C. A., Watanabe, G.; **Writing – review & editing:** Laranjeira, H. F., Santos, C. S., Reis, A. C. A., Silva, L. F., Silva, L. L., Pietrocola, M., Watanabe, G.

Data Availability Statement

The data will be provided upon request.

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