Paradigm for teaching the nuclear area in the brazilian basic education cycle - promoting learning

Paradigma do ensino da área nuclear no ciclo básico brasileiro - fomento ao aprendizado

Paradigma de enseñanza del área nuclear en el ciclo básico brasileño - promoviendo el aprendizaje

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Madison Coelho de Almeida
PhD student in Nuclear Technology
Institution: Institute of Energy and Nuclear Research
Address: São Paulo, São Paulo, Brazil
E-mail: madisonalmeida@hotmail.com

Donizete dos Santos Santana
MsC. in Education
Institution: Universidade de Taubaté
Address: Taubaté, São Paulo, Brazil
E-mail: santanadss6@fab.mil.br

Cesar Augusto Eugenio
PhD in Education
Institution: Universidade de Taubaté
Address: Taubaté, São Paulo, Brazil
E-mail: cesar.aeugenio@unitau.br

Delvonei Alves de Andrade
PhD in Nuclear Technology
Institution: Institute of Energy and Nuclear Research
Address: São Paulo, São Paulo, Brazil
E-mail: delvonei@ipen.br

ABSTRACT
This paper explores ethical and social aspects of nuclear technology in education, focusing on preparing teachers and students to address controversial issues and debates, as well as the role of education in shaping public opinion on nuclear issues. Pedagogy scholars highlight the importance of scientific literacy in the education of citizens, with discussions on the ethical and social implications of technologies, promoting critical thinking, as well as reinforcing the need for

adequate training for teachers on complex topics. At the same time, authors who dedicated themselves to the ways in which nuclear education can be present in the Brazilian basic education cycle raised important aspects in their analyses. It is noteworthy that the country's documentary panorama supports this issue, lacking effective mechanisms for its implementation. Through an introduction, literature review, methodology, findings, discussion, approach to challenges, opportunities and a conclusion, we seek to understand how curricula can be reformulated and educators better prepared for teaching nuclear energy to children and youth.

Keywords: Scientific Education. Nuclear Energy. Teacher and Student Training. Public Opinion.

RESUMO

O artigo explora os aspectos éticos e sociais da tecnologia nuclear na educação, concentrando-se na preparação de professores e alunos para abordar questões e debates controversos, bem como o papel da educação na formação da opinião pública sobre questões nucleares. Estudiosos da pedagogia destacam a importância da alfabetização científica na formação dos cidadãos, com discussões sobre as implicações éticas e sociais das tecnologias, promovendo o pensamento crítico, bem como reforçando a necessidade de formação adequada dos professores em temas complexos. Ao mesmo tempo, autores que se dedicaram às formas como a educação nuclear pode estar presente no ciclo básico da educação brasileira levantaram aspectos importantes em suas análises. Ressalta-se que o panorama documental do país respalda esta questão, carecendo de mecanismos eficazes para sua implementação. Através de uma introdução, revisão da literatura, metodologia, conclusões, discussão, abordagem aos desafios, oportunidades e uma conclusão, procura-se compreender como os currículos podem ser reformulados e os educadores melhor preparados para o ensino da energia nuclear a crianças e jovens.

Palavras-chave: Educação Científica. Energia Nuclear. Formação de Professores e Alunos. Opinião Pública.

RESUMEN

Este artículo científico explora los aspectos éticos y sociales de la tecnología nuclear en la educación, centrándose en preparar a profesores y estudiantes para abordar cuestiones y debates controvertidos, así como el papel de la educación en la formación de la opinión pública sobre cuestiones nucleares. Académicos de la pedagogía destacan la importancia de la alfabetización científica en la formación de la ciudadanía, con discusiones sobre las implicaciones éticas y sociales de las tecnologías, promoviendo el pensamiento crítico, además de reforzar la necesidad de una formación adecuada de los docentes en temas complejos. Al mismo tiempo, autores que se dedicaron a las formas en que la educación nuclear puede estar presente en el ciclo de educación básica brasileño plantearon aspectos importantes en sus análisis. Es de destacar que el panorama documental del país respalda este tema, careciendo de mecanismos efectivos para su implementación. A través de una introducción, revisión de la literatura, metodología, hallazgos, discusión, enfoque de los desafíos, oportunidades y una conclusión, buscamos comprender cómo se pueden reformular los planes de estudio y preparar mejor a los educadores para enseñar energía nuclear a jóvenes.

Palabras clave: Educación Científica. Energía Nuclear. Formación de Profesores y Estudiantes. Opinión Pública.

1 INTRODUCTION

Nuclear technology is a field that raises a wide range of ethical and social discussions due to its potential for both significant benefits as, unfortunately, for armamentist risks. Nuclear power can offer a relatively clean and efficient source of energy, be applied to health and industry, but also raises serious concerns regarding safety, radioactive waste management and the proliferation of nuclear weapons. In the educational context, the inclusion of nuclear topics in the curriculum requires a careful approach, in order to ensure that students receive balanced information and can develop a critical understanding of the impacts and implications of nuclear technology (Brasil, 2017).

This article examines the ethical and social challenges of teaching nuclear technology, the preparation teachers need to address such issues, and the critical role of education in shaping an informed public opinion. Through a literature review and critical analysis, we seek to understand how educators can be better prepared to teach about nuclear energy in a responsible and informed manner, and discuss the challenges and opportunities of this task; which is contemplated in Brazilian legal provisions and also in an interdisciplinary curricular approach.

2 LITERATURE REVIEW

Osborne and Dillon (2008) highlight the importance of scientific literacy in the formation of citizens, capable of participating in informed public decisions on complex technological issues. In this sense, education on nuclear technology should not only be informative, but also formative, preparing students to deal with ethical dilemmas and make future decisions. Reiss (2006) reinforces this view by stating that science education should include discussions about the ethical and social implications of technologies, allowing students to develop critical thinking and a deep understanding of the issues involved. Pereira; Bouzada Filho; Neves (2009) cite Brazil's choice for nuclear energy; due to Brazil having the sixth largest uranium reserves in the world, enough to ensure independence in the supply of this fuel. The authors also cite the fact that nuclear energy accounts for more than 2% of Brazil's energy matrix. Furthermore, in a survey conducted, high school students were not fully informed about the subject of nuclear energy. Zeidler (2009) emphasizes the need for adequate preparation of educators to deal with controversial issues and ethical debates. The author argues that teachers need specific pedagogical tools to facilitate discussions on complex and often polarizing topics, such as nuclear energy. According to the National Curricular Parameters for Secondary Education (PCNEM), there is an understanding that Physics must be re-discussed, enabling adequate understanding of the world and also citizenship formation, in a context of knowledge integrated into the student's life.

3 METHODOLOGY

There is a wide range of literature available on the nuclear issue in Brazil. Specifically, this study sought to support the work with bibliographical material, which is therefore an exploratory and documentary research. The aim was to identify difficulties and challenges faced, especially by teachers and students, through previously published studies. Thus, the work was supported by articles that addressed the issue in conferences and periodicals, as well as by federal legislation. The subject's adherence and intersection with the teaching of Science or Physics can be seen, in Brazilian Elementary or High Schools. Thus, the current research was carried out by what was explored by Brazilian academics, in different Units of the Federation, sometimes with geographic approaches in municipalities. The time horizon of the research extended to the first two decades of the 21st century.

An interdisciplinar approach was considered in this study. In terms of interdisciplinarity, combined with didactic preparation, Guimarães (2013) emphasizes the favorable issues regarding the generation of nuclear energy, whether due to the nuclear matrix supporting the population's projected energy demand until 2050, or due to the tonnage of fossil emissions avoided with this nuclear generation.

4 FINDINGS AND DISCUSSION

The National Curricular Parameters (PCN) of the Brazilian Ministry of Education – MEC (1999, 2002) highlight the importance of approaching contemporary themes, such as nuclear energy, through methodologies that encourage critical and reflective analysis, such as case studies. These parameters provide guidelines for teaching Science, highlighting the importance of approaching contemporary issues, such as nuclear energy, in a critical and reflective manner. However, it is necessary to invest in teacher training and in providing updated and accessible educational resources. A historical review of the legal frameworks in education in Brazil shows us that the Brazilian Federal Constitution (CF) of 1988 conceived the existence of a curricular base for the country. The State was motivated by school dropout and repetition rates, and the search for an adequate standard of quality in education was already visible.

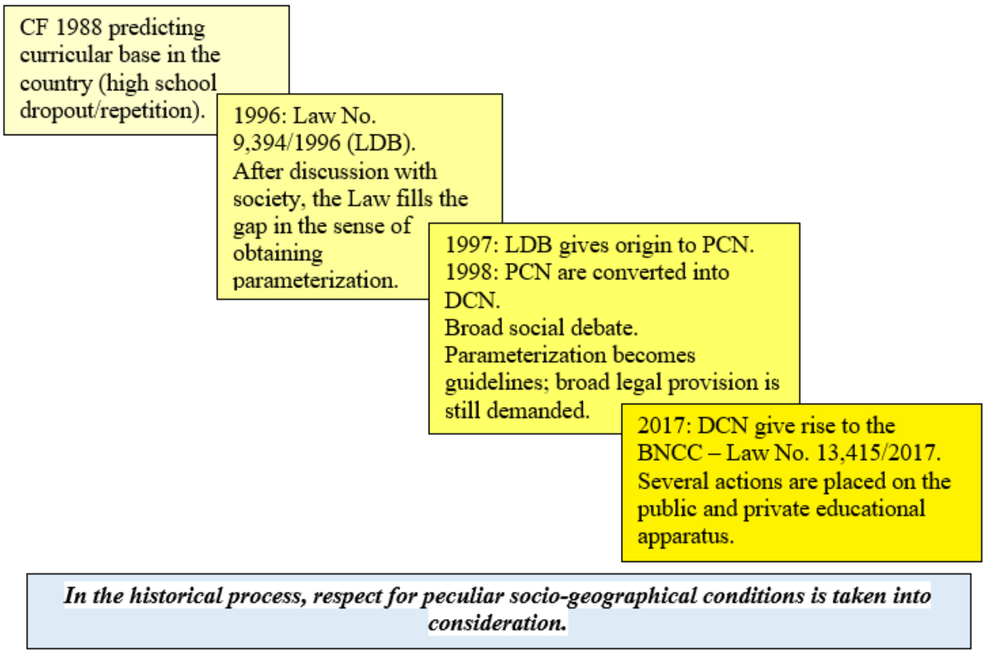
In 1995, proposals for curricular parameterization began to circulate in the educational environment. In 1996, the Law of Guidelines and Bases of National Education (LDB) was enacted – improving the responsibilities of the public sphere over education. In 1997, the LDB resulted in the publication, by the MEC, of the National Curricular Parameters (PCN). These parameters would serve as a reference for the renewal of the school curriculum, providing opportunities for the specificity of early childhood and elementary education. After the establishment of the PCN, debates were held by academia and educational institutions, together with the government. A reassessment of the didactic production to be used in schools then took place. Each entity is allowed to work on the curriculum according to the local reality, using the PCN as a reference; in addition to mentioning the necessary initial and ongoing training of teachers. Cross-cutting and current themes are introduced: Ethics, Cultural Plurality, Health, Environment, Sexual Orientation.

The High School National Curriculum Guidelines (PCNEM) date back to 2000 and have a different dynamic when compared to the Elementary School National Curriculum Guidelines. They are divided into four parts, discussing target areas after Elementary School, namely: Languages, Codes and their Technologies; Mathematics and their Technologies; Natural Sciences and Human Sciences and their Technologies. The Complementary Educational Guidelines for the National Curricular Parameters (PCN+), published in 2002, represent a complement to the PCNEM. It involves teacher training, seeking direct dialogue with educators, enabling a meeting between ideas and their implementation. The document systematically organizes the proposals intended by the PCNEM. Thus, the PCN+ suggest the organization of classes and courses, in addition to multiple approaches within the same subject. Pereira; Bouzada Filho; Neves (2009) discuss the PCN+, highlighting Physics as having been constructed throughout the history of humanity, as scientific knowledge rich in cultural and social contributions; resulting in the evolution of different and also driven by these.

A series of debates began in 1997 and 1998, which resulted in the issuance by the MEC of the National Curricular Guidelines (DCN) in 1998. At this point, what had only been parameterized began to exist, improved, in the form of guidelines. Among them: (i) literacy occurs up to the 3rd year of elementary school; (ii) the areas of knowledge are divided into: Art, Natural Sciences, Geography, History, Mathematics, Portuguese Language and Physical Education.

In the context of the DCN, there is an improvement in its approach: CNE/CEB Resolution No. 1, of July 5, 2000; this establishes specific National Curricular Guidelines for Youth and Adult Education. With the subsequent publication of the National Common Curricular Base (BNCC) in 2017, Brazil now has a normative document, consolidating what was already foreseen at the level of PCN and DCN. The BNCC incorporated concepts such as skills, attitudes and values that are essential to children and young people. In this sense, all schools in Brazil need to have their own Political-Pedagogical Project (PPP) aligned with the BNCC. Figure 1 provides a historical sequence on the topic.

Figure 1. Chronology of the main educational legal frameworks and their contexts



Source: the authors

4.1 COMPETENCIES AND SKILLS IN THE NATIONAL COMMON CURRICULAR BASE

If the BNCC (Brasil, 2017) competencies and their impact on teaching are considered, there is adherence to the proposal for contextualized, current teaching that includes core competencies and others in curricula. As showed.

> 1. Value and use historically constructed knowledge about the physical, social, cultural and digital world to understand and explain reality, continue learning and collaborate towards the construction of a fair, democratic and inclusive society.
> 2. Exercise intellectual curiosity and use the approach specific to science, including research, reflection, critical analysis, imagination and creativity,
> [...]
> 10. Act personally and collectively with autonomy, responsibility, flexibility, resilience and determination, making decisions based on ethical, democratic, inclusive, sustainable and supportive principles.

Macedo and Fini (2018) deal with skills from the perspective of the BNCC, with these divided into practices, cognitive, social. Practices, in terms of applying knowledge to solve problems; identifying data on a given problem, seeking a solution. In terms of finding solutions and critical, reflective thinking, core teaching fulfills its role, working on practical skills in the student. Thus, intellectual curiosity remains present here; in a proposal that combines content, notably from the teaching of Physics and nuclear energy. A proposal for teaching nuclear technology, especially in secondary education (high school), should bring possibilities to the benefit of the population, such as radioisotopes in diagnostic and therapeutic medicine; in agriculture and food, with tracer mechanisms; in mining, industry and the environment with dosage systems and others. Macedo and Fini (2018) emphasize the BNCC promoting the right to the full exercise of citizenship, overcoming the fragmentation of educational policies; strengthening collaboration between the three spheres of government (federal, state, municipal); guaranteeing students' right to learn and develop increasingly.

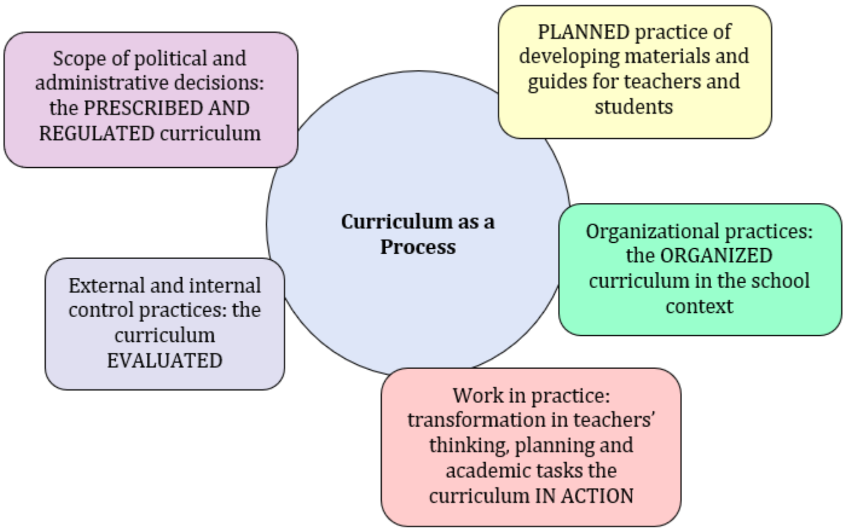
4.2 THE SCHOOL CURRICULUM AND INTERDISCIPLINARITY

Vartuli (2023) quotes Tenório (2015), in an analysis of nine of the most widely used schoolbook collections in the Brazilian public school system, finding that most of the books used did not meet the guidelines of the Ministry of Education. Among the problems highlighted, were the lack of a historical approach; interdisciplinarity and discussion of social aspects. However, the theme of nuclear energy is multidisciplinary and, therefore, must bring together concepts, content and skills, whether those found in science teaching (in the elementary cycle), or those found in High School; in the learning of Physics and also Chemistry. Some textbook content does not allow students to fully understand the political, economic, technological and social aspects of nuclear science, benefits, adds Vartuli (2023), as well as the procedures and alternatives for managing this energy are little discussed. Tekin and Nakiboglu (2006, *apud* Silva; Campos; Almeida, 2013) speak of Nuclear Physics and Chemistry as a whole that can be seen as a nuclear science; and studies arising from this Science contribute significantly to the understanding of the nature of matter. This can, no doubt, converge towards the convenience of interdisciplinarity.

Silva; Campos; Almeida (2013) also demonstrate that the topic of radioactivity should be an integral part of the curricula of Secondary and Higher Education in Chemistry in Brazil; it is even recommended in the National Curricular Guidelines (Brasil, 2006). According to the research by Silva; Campos; Almeida (2013), articles were found that provide contributions on teaching strategies for learning concepts of radioactivity. Samagaia and Peduzzi (2004, *apud* Silva; Campos; Almeida, 2013) analyzed a teaching module using role-playing games (RPG) with elementary school students, using the history of the Manhattan Project in the USA.

Silva (2010, *apud* Andretta, 2013) cites the validity of the domain of knowledge that must be taught, in terms of having the curriculum as the center of pedagogical practice, making it possible to discuss and define what knowledge is and what should ultimately make up the school curriculum. From the same perspective, Young (2007, *apud* Andretta, 2013) questions whether the school system addresses an elaborated curriculum becoming means for students to acquire powerful knowledge, from a socially stimulating perspective: economically disadvantaged students actively participating in learning "may be the only opportunity to acquire powerful knowledge and be able to move, at least intellectually, beyond their local and particular circumstances" (Young, 2007, *apud* Andretta, 2013, p. 98). Zabala (2002) mentions interdisciplinarity as a vector of integration and establishment of links, providing complementarity and cooperation between different methodological instruments. Bes *et al.* (2020) deals with the contemporaneity of the theme; with this inserted in the proposal of the curriculum; the same way, he takes up the idea of education in the social context. A value-based tool, linked to the political-pedagogical act, allowing the construction of a panorama of a lived reality, in different dimensions. As in figure 2.

Figure 2. Curricular dimensions



Source: adapted from Trevisan and Mendes (2015, *apud* Bes *et al*., 2020, p. 3)

The so-called scientific, technological and social (STS) methods, perfectly in line with a proposed school curriculum that encompasses nuclear technology, are discussed by Pereira and Galindo (2023). The authors cite the historical context of this movement, which emerged between the 1960s and 1970s, when science was seen as something neutral and little dialogued with the social processes in which it was immersed. Santos and Mortimer (2002, *apud* Pereira and Galindo, 2023, p. 17) cite STS as a perspective that deals with the "interrelations between scientific explanation, technological planning, problem-solving, and decision-making on practical issues of social importance". The same authors also mention that school curricula that deal with the STS perspective present a conception of:

> (i) science as a human activity that attempts to manage the environment and ourselves, and that is closely related to technology and social issues; [...] (iii) a student as someone who is prepared to make intelligent decisions and who understands the scientific basis of technology and the practical basis of decisions.

Thiesen (2008) mentions that interdisciplinarity is confused with the dynamics of knowledge. The author mentions the inconvenience of a "trench war" among academics, since interdisciplinarity is situated in overcoming the fragmented sciences and knowledge produced by them. Thiesen (2008) also describes how the development of truly interdisciplinary experiences is still in its infancy, although it is recognized that there is an institutional effort in this direction. The author cites as some reasons for this limitation the fragmented way in which school curricula are structured, as well as the disciplinary model, disconnected from training in universities. Themes bringing interdisciplinarity also bring out the subject closer to its reality; they help students to understand conceptual networks, enabling "greater meaning and sense to the learning contents, allowing a more consistent and responsible education" (Thiesen, 2008, p. 551). Reis (2017) describes the school curriculum as constituting a vector of critical interculturality in schools; due the fact that it is intrinsically linked to the students' educational path. According to the author, an intercultural education encompasses the complexity of human experiences, circumscribed in a complex historical and social universe.

4.3 ETHICAL AND SOCIAL ASPECTS - TEACHER PREPARATION WITH CASE STUDIES AND ANALYSIS

Vartuli (2023) highlights that, in a "post-Chernobyl" (1986) and "pre-Fukushima" (2011) world, a survey on energy and the environment, conducted in Japan in 1998, with high school students, showed that only 38% provided correct answers to a questionnaire on topics related to nuclear energy. In comparison, in a similar study in Europe, the accuracy rate was 60%. Given that Japan was a country with a great share of nuclear in its energy matrix, these data are quite interesting. In another Japanese survey as well, mentioned by the author, only 11% of students had contact with the topic "nuclear energy" during classes. Detailed investigation, aiming to understand the scenario, showed that among the main causes was a passive attitude on the part of teachers, who omitted sections of the books focused on nuclear energy in classes, or even superficially addressed this subject. A comparison between the curricula of bachelor's and licentiate degrees shows a significant difference in content and level, with Modern and Contemporary Physics practically non-existent in undergraduate courses, in technological field. The author emphasizes that this difference makes it difficult for some graduates to continue their studies at the postgraduate level.

A project developed by the International Atomic Energy Agency (IAEA) in partnership with countries in the Middle and Far East, such as Malaysia, Indonesia, the Philippines and the United Arab Emirates, trained fifteen teachers from these nations about nuclear culture, according to Vartuli (2023), from the production of teaching materials to comprehensive activities, such as proposals for curricular changes and also the creation of nuclear knowledge museums. Upon returning to their countries, the professionals trained another 1,364 teachers, who passed on their knowledge to a universe of 24,717 students. Gomes (2013, *apud* Lucena *et al.,* 2017) found that teachers felt insecure when addressing Modern and Contemporary Physics (MCP). There were Physics teachers and undergraduate Physics students at the time of the research. Among the participants' responses, it was worth noting that five said they had studied MCP satisfactorily in their undergraduate studies, but there was no approach on how to work with “nuclear energy” in high school. As highlighted by Alexandre (2003), studies offer the opportunity to analyze real situations, such as the nuclear accidents in Chernobyl and Fukushima, which provide crucial insights into the risks associated with nuclear energy. This is essential for students to understand not only the technical aspects, but also the ethical and environmental issues involved in the use of this technology. The use of case studies can also foster in-depth discussions on environmental sustainability and ethical issues related to nuclear energy. As noted by Barbieri (n.d.), by exploring the role of nuclear energy as an alternative to fossil fuel sources, students can be challenged to consider the long-term environmental impacts and ethical concerns associated with the choice.

Authors such as Osborne and Dillon (2008) emphasize that case studies are essential to promote quality science education, which goes beyond the mere transmission of information, encouraging students to develop critical thinking and analysis skills. Nuclear energy presents dilemmas, ranging from safety, accident prevention, radioactive waste management and measures to prevent war proliferation. In order to have these topics to be addressed in a balanced and effective manner, it is essential that teachers are well equipped and prepared.

Silva; Campos; Almeida (2013) worked on the way students understand issues related to radioactivity, as well as the way in which didactic texts address such content. The analysis of the imagination of undergraduate students in Physics was discussed by Sorpreso and Almeida (2010, *apud* Silva; Campos; Almeida, 2013), from the point of view of the history of science. The authors add, stating that it would be "expected that the topic on teaching radioactivity for third grade would have a greater number of articles, as radioactivity is considered by the PCN+ as one of the structuring themes" (Silva; Campos; Almeida, 2013, p. 55).

4.4 THE ROLE OF EDUCATION IN RAISING INFORMED PUBLIC OPINION

According to Zeidler (2009), initial and continuing teacher training should include specific modules on nuclear ethics, as well as pedagogical techniques that allow them to facilitate open and respectful debates. The inclusion of ethical and controversial topics in science teaching is not only an educational trend, but a necessity for the development of complete scientific literacy. Reiss (2006) argues that science education should incorporate discussions on the moral implications of technologies, thus facilitating the formation of a well-informed and critical public opinion. The raising of an informed public opinion on nuclear issues is a crucial aspect for the development of appropriate policies and decisions regarding nuclear technology. According to Alexandre (2003), education plays a vital role in this process, providing students with a curriculum that includes case studies, debates and critical analyses, all of which contribute to a deeper understanding of the implications of this technology.

The way teachers perceive and teach these concepts can significantly influence the formation of an informed public opinion among students. Authors such as Jiménez and Peña (2019) highlight the importance of teachers' beliefs in the way science is thought, including nuclear technology. Through well-structured curricula, educational initiatives and active teacher engagement, students can develop critical skills and a deep understanding of the challenges and opportunities associated with nuclear technology, thus contributing to a more informed and deliberative public debate.

5 CHALLENGES AND OPPORTUNITIES IN THE IMPLEMENTATION OF NUCLEAR TECHNOLOGY EDUCATION

The challenges for teaching and learning in a rich topic such as the one here proposed involve varied mechanisms; from searching for and enhancing content, to applications that involve the student. Fernandez *et al.* (2021) presents a systematization carried out in terms of learning paths, with topics in Nuclear Physics, which come to the aid of educators and in coherence with the BNCC. This is showed in table 1, with codes (skills) and also types of quiz associated to the topics. The interdisciplinary way is herein expressed; with codes "CNT" (Science & Technology) to "MAT" (Mathematics) associated.

Table 1. Learning Trail: Nuclear Physics

Subsection	Quiz	Skills	Content
Atomic Models	RadQuiz 6	EM13CNT201	Evolution of the atomic models
Nucleus and Instability	RadQuiz 7	EM13CNT209	Radiation (elementary particles; nuclear strong force; nuclear weak force nuclear fission; standard model)
Radioactive Decay	RadQuiz 8	EM13CNT104	Energy quantization, atomic nucleus, radioactivity, nuclear fission; radioactive decay
		EM13CNT209	Radiation
		EM13MAT304	Radioactive accidents
		EM13MAT306	Nuclear accidents
Decay Law	--	EM13MAT305	Problems with logarithmic functions
Activity and Half Life	--	EM13CNT304	Nuclear energy. Radioactive decay

Source: adapted from Fernandez *et al.* (2021, p. 5)

The PCNs (Brasil, 1999, p. 28) reflect the need for critical thinking, as well as knowledge of advances in terms of medical diagnosis; implications of an accident involving ionizing radiation; options for different forms of energy, among other issues.

> "[...] evaluate the risk/benefit ratios of a given medical diagnostic technique, the implications of an accident involving ionizing radiation, the options for using different forms of energy, the choices of procedures that involve less environmental impact on the greenhouse effect or the ozone layer, as well as the discussion on the participation of physicists in the manufacture of atomic bombs".

The same document highlights the need for modern Physics, to be taught in line with everyday themes, which provide students with practical knowledge (Brasil, 1999, p. 23).

> "A Physics that explains the costs of the "electricity bill" or the daily consumption of fuel and also the issues related to the use of different energy sources on a social scale, including nuclear energy, with their risks and benefits. A Physics that discusses the origin of the universe and its evolution".

Macedo and Fini (2018) state that school knowledge should not be understood as something disinterested and erudite, or as an end in itself. On the contrary, education is committed to global, holistic human development, in the intellectual, physical, emotional, social, ethical, and moral dimensions. The goal of education is the integration of children and young people into the world. Implementing nuclear technology education faces significant challenges ranging from the availability of resources to overcoming social prejudices. As highlighted by Alexandre (2003), the lack of adequate teaching materials and specialized training for teachers can limit the effectiveness of education in this area. In addition, prejudice and fear towards nuclear energy, widespread in society, can hinder the acceptance and implementation of educational programs on the theme. Studies have been conducted into how "radiophobia" – an unfounded fear of nuclear energy or radioactivity – mystifies and impairs understanding.

The availability of adequate resources and ongoing teacher training are essential aspects to ensure that nuclear technology teaching is approached objectively. As Jiménez and Peña (2019) point out, it is essential that these efforts be complemented by government policies that encourage investment in quality science and technology education. In addition to practical challenges such as resource availability and teacher training, there are also ethical and political issues involved in teaching nuclear technology. As Paschoa (2000) notes, it is crucial to promote a transparent and inclusive public debate on these issues, ensuring that decisions related to nuclear energy are made in an informed and democratic manner.

In short, implementing nuclear technology education requires a joint effort by educational institutions, governments and civil society to overcome challenges, ranging from teacher training to public awareness. Only then it will be possible to ensure quality education that prepares students to understand and face the complex challenges of the contemporary world. Despite the challenges, nuclear technology education offers significant opportunities to foster a more comprehensive understanding of issues related to energy security and sustainability. As highlighted by Jiménez and Peña (2019), nuclear energy education can contribute to a deeper awareness of energy sources and their environmental, social and economic implications. Furthermore, implementing nuclear technology education can prepare students for careers in related fields such as scientific research, nuclear engineering, and energy management. As noted by Reiss (2006), the advancement of nuclear science and technology depends on the recruitment and training of a new generation of skilled professionals. Therefore, investing in education in this area not only expands students' knowledge but also contributes to progress and innovation in these disciplines. The National Curricular Guidelines established by the Brazilian Ministry of Education (1999, 2002) recognize the importance of including nuclear technology in the school curriculum as an integral part of students' scientific and technological education.

Pereira and Galindo (2023) clarify advances that, acting as milestones in the nuclear trajectory over time, can be considered didactically. In this context, the following is cited chronologically:

- 1896 – Discovery of Radioactivity, in France;
- 1939 – Discovery of Nuclear Fission, in Germany;
- 1945 – Bombing of Hiroshima and Nagasaki by the USA, in Japan;
- 1951 – The first Nuclear Reactor to generate electrical energy was opened in Idaho, USA;
- 1956 – The first Nuclear Power Plant was opened in the United Kingdom;
- 1979 – Three Mile Island accident, in the USA;
- 1982 – Inauguration of the Angra 1 Nuclear Power Plant;
- 1986 – Chernobyl accident, Soviet Union;
- 2000 – Inauguration of the Angra II Nuclear Power Plant;

Add to the list the event in Fukushima, Japan, in 2011. Such events, in a pedagogical trend, serve as clarification in classrooms. Even in the context of nuclear energy safety.

5.1 DEMYSTIFYING ISSUES

Nuclear Energy has advantages that make it an option when compared to other energy sources. This is what Pereira and Galindo (2023) quote. Among these advantages, we can highlight the large-scale presence of uranium in several places, including Brazil, in addition to the low operating cost of a nuclear plant, which does not emit polluting or greenhouse effect gases, has high automation, occupies reduced areas, in addition to operating continuously, favoring its dispatchability. Questionnaires on the topic of "nuclear energy" were addressed to students in Rio de Janeiro (Pereira; Bouzada Filho; Neves, 2009) and, among 115 students interviewed, the results were unequivocal: 87% of the students had never had information on the topic in class; 72% reported having some information through the media; 60% associated the trefoil – the international symbol of radioactivity – with nuclear energy; 38.5% located the nuclear power plants in Angra dos Reis and 31.5% said they did not know the location of the plants. In the question "What reminds you of nuclear energy?", 40% associated it with bombs, accidents or cancer. Prejudices are related to negative perceptions, arising from ignorance or lack of adequate knowledge of nuclear energy. "Today's society demands that critical and capable citizens be formed in decision-making and that they can actively participate in the environment in which they are inserted in" (Almeida, 2018, *apud* Pereira and Galindo, 2023, p. 18).

Studies such as "Investigating Nuclear Energy in the Classroom" (PUCRS, 2023) and "Nuclear Energy and the Brazilian School Curriculum" (Meer, 2023) indicate that the pedagogical approach must be balanced, providing students with a comprehensive and critical understanding of energy features and nuclear technology. France is the largest nuclear energy operator on the planet (56 reactors), without ever having experienced a nuclear accident in its history. The advantages outweigh the disadvantages, and it seems to us that the big issue lies in demystifying concepts. This is what Guimarães (2019) tells us.

> Unfortunately, nuclear energy was effectively unveiled to the world with the atomic bomb; overshadowing the enormous advances it made for society, especially in medicine. If electric energy had been born with the electric chair, we would certainly have had great resistance to it as well.

The need for demystification becomes clear in the research of Fernandez *et al.* (2021). It brings reactions provoked in students; these ones with different educational backgrounds, about what feeling is awakened regarding the word "radioactivity". The largest dimensions representing more records. As showed in figure 3.

Figure 3. Portuguese word-cloud, created after anonymous research

Source: Fernandez *et al.* (2021, p. 2)

6 CONCLUSION

This paper examines challenges and opportunities in teaching nuclear technology, highlighting the need for ongoing teacher training and a curriculum that promotes scientific and ethical literacy. Nuclear technology in education represents a unique opportunity to educate students about a highly relevant scientific field that can have a profound impact on society and the environment. However, this approach also brings with it significant ethical and social challenges that need to be carefully considered. As highlighted by several experts, including Alexandre (2003) and Jiménez and Peña (2019), adequate teacher preparation is essential to conduct informed and balanced discussions on these sensitive topics.

Through education on nuclear technology, students have the opportunity not only to understand the underlying scientific principles, but also to reflect on the ethical and social implications of this technology. This is essential to cultivate an informed public opinion, capable of participating critically and consciously in debates on nuclear energy and its applications. However, achieving these objectives requires a joint and continuous effort in the training and updating of educators.

The National Curricular Parameters established by the Brazilian Ministry of Education recognize the importance of including nuclear technology in the school curriculum, thus providing a guide for the development of teaching plans in this area. However, as highlighted by Barbieri (n.d.), it is necessary to go beyond the curricular guidelines and ensure that teachers have access to adequate resources and opportunities for professional development. It is crucial that an open and collaborative dialogue be held between educators, researchers and educational authorities to address the challenges and maximize the benefits of nuclear technology education.

Ultimately, the success of nuclear technology education depends on the ability to effectively integrate the scientific, ethical and social dimensions of this complex field. Only through a joint commitment to educating a new generation of critical and informed citizens we can address the global challenges related to energy and the environment. Mechanisms are already in place and can be improved. This should be the basis for curricular adaptation or reformulation that converges on a topic as current and necessary, as the demystified and scientific teaching of nuclear energy. The school curriculum should have an interdisciplinary emphasis, since Physics or Sciences should be related to Chemistry and other areas of knowledge, so the study of an energy source involves various types of knowledge and interpretations. Preparing teachers for such teaching will contribute to the formation of critical citizens and, consequently, to an impartially informed public opinion. A curriculum that reflects adequate pedagogical practice requires covering nuclear energy content in an enlightening and non-mystifying manner.

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