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REVIEW ARTICLE

Panorama and Perspectives of the Teaching of Radiation and Radioactivity at the High School Level

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ABSTRACT

This paper presents a perspective of how the radiation and radioactivity themes have been discussed at the high school level in several locations around the world. In this context, scientific journals, academic journals, theses, dissertations, and media materials were analyzed. Recent research has shown that the concern with the discussion about radiation and radioactivity in basic education is a current and global issue. The discussion on the radiation and radioactivity themes in different contexts in this paper was presented in four parts: (i) The representations used to deal with the themes; (ii) how the high school curriculum deals with the topic; (iii) the common alternative conceptions; and (iv) intervention proposals to address the issues. Based on a literature review, to collaborate in the teaching of radiation and radioactivity topics, the main objective of this work is to understand the current scenario on these topics, identify some challenges to understand them, and present possible interventions to overcome them.

KEY WORDS: Alternative conceptions; high school; literature review; radiation; radioactivity

INTRODUCTION

In the past century, the scientific community experienced a moment of rupture of paradigms in the field of physics, being currently defined in two distinct periods, classical, and modern (Fara, 2014). The discoveries in this period had a great impact on history, not only in the scientific field but also in the social field. Based on this, a demand has been identified in addressing issues of modern physics, since they are the basis of current scientifi and technological development. However, what is verified is that in many cases, the physics classes are restricted to contents that go until the end of the XIX century, making it difficult to establish a relationship between what is learned in the classroom and the reality external to it (Costa and da Silva Santos, 1995).

We know that science developed in a society marked by a great dispute between world powers, whose major milestone was the development of weapons capable of destroying cities and causing lasting environmental damage, that is, atomic bombs (Fara, 2014). In addition, studies in relation to radioactive materials have allowed the construction of nuclear power plants as a means of producing energy, but in recent decades, accidents at these plants have brought to the surface a certain distrust regarding this technology (Maharaj-Sharma, 2011). Despite these controversial points, scientific development in the field of radiation has brought great advances in medicine, helping both in diagnoses and treatments, such as computed tomography and radiotherapy (Keevil, 2012). In any case, contemporary society lives surrounded by radiation, that is, in addition to the radiation sources already existing in antiquity, the technological advance of the past century brought with the age of communication an environment even more immersed in electromagnetic waves. Thus, it is noted that the theme not only has a great impact on today's society but also carries different connotations according to the context, in which it is inserted.

Within this context, both radiation and radioactivity are controversial topics and carry with them an emotional burden that must be taken into account in the teaching of physics (Maharaj-Sharma, 2011). The media has a strong relationship with the youth's view on the subject, not only in the dissemination of inaccurate information but also through films and fictional stories (Tuzón and Solbes, 2016). The difficul ies involved in teaching physics in the classroom, linked to superficial, or incorrect information about a certain phenomenon can favor the development of alternative concepts in students (Thompson and Logue, 2006). Addressing these alternative concepts allow the teacher to create a teaching environment, in which the student is led to experience a clash of ideas. Therefore, the student from experiences outside the school environment, when faced with scientific knowledge presented by teachers, which presents a better learning of the subject in question (Neumann and Hopf, 2012).

According to Cardoso et al. (2016), based on the importance of social character in scientific development as proposed by teaching with a Science, Technology and Society (STS) focus, it is necessary to propose teaching based on the reality of the student. In other words, the need for a change in the teaching of physics is clear, not only of the topics to be discussed but also in the way this is done.

Based on the problem discussed so far, science educators around the world have been dedicating their efforts to studying the understanding of basic education students on the topics of radiation and radioactivity, as well as proposing interventions that favor the learning of these topics. Considering that, this work aimed to present an overview of the obstacles that arise when teaching radiation and radioactivity as curriculum subjects and what to do about them. We collected and analyzed documents from various countries aiming to gather perspectives from different cultures and educational systems. From that, to present a selection of articles that gave a widespread overview of the aforementioned topics, a rigorous literature search process was adopted to ensure reliability. Reliability is based on selected databases, publications, period covered, and keywords used for the literature searches. In this work, keywords such as "radiation and radioactivity," "modern physics," and "high school" were used to focus on relevant studies in the 1990–2020 period. The Scielo, Web of Science, Scopus, and Science Direct databases were the most used. This paper is separated into four sections: (2) Representation of the theme in different contexts, (3) high school Physics curricula, (4) alternative conceptions, and (5) intervention proposals. We hope that this overview from different perspectives help teachers to choose the best approach to improve their students learning.

Representation of the Theme in Different Contexts

The inclusion of modern physics in basic education is already part of a widespread discussion and seen as a necessary measure (Pietrecola, 2005). In this context, the discussion on radiation and radioactivity is also inserted, due to the direct interference of these topics in today's society. This relationship between radiation and current events can be evidenced by the way the subject that is presented by the media, in films, series, and the news (De Oliveira et al., 2007 and Tuzón and Solbes, 2016). Part of this repercussion is related to the disasters that have occurred in recent decades, often promoting a negative view on the use of radiation (Tomkiv et al., 2016). In any case, it is understood that it is necessary to reflect on how radiation is discussed by different media outlets.

In this context, Tomkiv et al. (2016) conducted an investigation into how European newspapers presented the radiological risk after the Fukushima accident. The work carried out with 1,340 newspaper articles from different countries focused on analyzing the content of the articles in a quantitative (verifying the use of radiation-related units) and qualitative (verifying how the risks were discussed). In general, it was identified that few articles used physical units and, in some cases, had more than one unit in the same text, without explaining them, which could cause confusion in readers not used to the language. It was also verified that instead of using the units, it was more frequent to compare fi ures with safety norms or background radiation, to symbolize the risks of a given radiation dose. From this, the authors conclude that there should be greater interaction between journalists and scientists so that the report on radiological risks could be improved.

In Brazil, a remarkable event in relation to radioactivity was the nuclear incident occurred in Goiania (Anjos et al., 2001; International Atomic Energy Agency, 1988). In this case, a sample of Cesium-137 chloride was found by scavengers in the rubble of the *Instituto Goiano de Radioterapia*. Due to the lack of knowledge regarding the dangers of the material, the source capsule was ruptured, the remnants of the source assembly were sold for scrap to a junkyard owner. Due to this, many people had contact with the sample resulting in one of the greatest radiological disasters in history, causing human, and environmental damage. Based on the importance of this event, Rosa et al. (2019) investigated the treatment of this subject in Physics textbooks recommended by Brazil's National Textbook Program 2015. It was identified that few authors mention the Goiânia disaster, and when they do, they are usually restricted to enumerating the facts with a historical character. Thus, in these publications, there is no reflection on how the event can be used to assist in the understanding of physical phenomena, or to develop a critical sense regarding the application of radiation in everyday life.

In these examples, it can be seen that information about the physics of radiation and radioactivity can be found in different sources, but in some cases, the discussion is shallow, and they stick to the pragmatic character of the content and can also present confusing information. There is also little concern with the socio-political aspect of the theme, leaving aside important discussions in the formation of a critical individual. This type of content available to students can interfere with their vision, also reflecting on their learning

High School Physics Curricula

Radiation and radioactivity appear in different contexts on contemporary society. However, when discussing these themes in the classroom, it is important to analyze if and how these topics are inserted in the curricula. Pietrocola (2005) showed how antiquated the Brazilian Physic curriculum was, limited to the 17th–19th centuries. In addition, Pietrocola (2005) highlighted the hierarchical and linear organization that considered a historical organization of the topics which made it difficult to insert modern physics in the curriculum. Recognizing the need for an update, seven themes were suggested by the author to be included in high school classes: (1) Spectrum lines, (2) Bohr's atomic model, (3) photoelectric effect, (4) energy emission-absorption processes, (5) Mach-Zender's experiment, (6) duality wave-particle, and (7) possible interpretations on the Quantum Theory.

The necessity to teach beyond the classical physics is not a local phenomenon. After a controversial introduction of quantum physics in the dutch national high school curriculum in 2014, Stadermann et al. (2019) performed an analysis on the curriculum of 15 different countries aiming to understand how quantum physics was presented. Stadermann et al.'s (2019) first conclusion was that the teaching of quantum physics in high school was present in all 15 analyzed curricula. Furthermore, even considering the different contexts and

approaches, Stadermann et al. (2019) were able to recognize a basic curriculum common to all countries composed of seven themes: Discrete energy levels (line spectra); interactions between light and matter; wave-particle duality or complementarity; matter waves, quantitative (de Broglie); technical applications; Heisenberg's uncertainty principle; and probabilistic or statistical predictions. The presence of a common approach based on a quasihistorical view that presents science as linear and ignores the complex path to a discovery was also evidenced (Stadermann et al., 2019).

Thus, it is possible to note that the uncertainties about the insertion of Modern Physics' topics in the high school curriculum were already resolved in various countries and that, among the covered topics, radiation and radioactivity are present. However, some obstacles are still to overcome when it comes to teaching these topics. Hence, further investigations on new approaches to improve the students learning are necessary.

Alternative Conceptions

A starting point for discussing radiation and radioactivity in basic education is through alternative conceptions. In this case, alternative conceptions are described as ideas that promote an incorrect understanding on any subject, based on the students' personal experiences (Thompson and Logue, 2006). In addition, these conceptions are also understood as knowledge about natural phenomena that differ from the scientific description, theories, and laws, used to describe the world around the student (Anam Ilyas, 2018; Maria et al., 2015).

Investigations on alternative conceptions began in the 1970s and are still the subject of research today (Gutiérrez et al., 2000). Such works in the area of education and science show that students' prior knowledge of natural phenomena must be considered for meaningful learning (Gutiérrez et al., 2000; and Nicolaides and Fernandes, 2008). In this same line of thought, many recent works point to the conceptions brought to the classroom by students as one of the most important things in the context of education (Griffiths and Preston, 1992; Neumann and Hopf, 2012; and Plotz, 2016). However, as pointed out by Bachelard (2002), science teachers generally disregard the fact that their students enter physics classes with some empirical knowledge obtained in their daily routine. This contrasts with the fact that they should be deconstructing the idea of knowledge structured in a purely empirical way, in favor of promoting a scientific culture based on dynamic and open knowledge. Nakhleh (1992) stated that once these mistakes are integrated into the student's cognitive structure, they directly interfere with the student's learning. According to Salame et al. (2011), alternative conceptions are developed in the early stages of students' learning and may generate resistance to the correct learning of ideas, because when presented to the true scientific concepts, the conflict with their alternative conceptions can generate difficulty in understanding the new information as it will seem incorrect to them.

Alternative conceptions are not restricted to a single content worked on in basic education, however, in relation to modern physics, factors such as the level of abstraction hinder learning. As for radiation specificall , even though in contemporary society everyone is surrounded by electromagnetic waves at all times, the fact that there are different types of radiation makes it difficult for people who are unfamiliar with the scientific knowledge to understand this phenomenon (Plotz, 2016).

To analyze the conceptions of radiation in general, Neumann and Hopf (2012) researched with 50 Austrian students, between 14 and 16 years old. These authors took as a starting point of their research the fact that the term radiation itself is something that is frequent in everyday life, as it is in news about nuclear energy, protection against ultra-violet radiation and the possible danger in the use of mobile devices. This way, Neumann and Hopf (2012) conducted, with each participating student, a semi-structured interview with eight questions, open and closed, to ascertain their thoughts regarding the term radiation. Their research pointed out that some students consider radiation as something unnatural and directly linked to devices invented by humans. At the same time, students did not establish a relationship between radiation and visible light, as if they were dealing with different phenomena. On the other hand, the idea that radiation was something emitted by living beings and allowed the perception of senses was also identifi d. There was also a strong idea that radiation was harmful, and it was related to environmental problems. As for the identification of different types of radiation, Neumann and Hopf (2012) found that students were familiar with the different types of radiation; however, there was some confusion between radiation and radiant particles.

Recognizing a scarcity of papers with more quantitative analyzes on the topic, Rego and Peralta (2006) conducted a survey, in Portugal, with 1,246 students from the seventh grade of basic education up to university level. In this study, the objective was to bring an analysis of the conceptions of Portuguese students, from different school levels, in relation to radioactivity, from a statistical viewpoint. The work in question was divided into two stages. The first part consisted of a questionnaire with "yes or no" questions, to find out how familiar the students were with the idea of radiation. In the second part of the research, statements had to be classified by the students by level of agreement or acceptance. From these two questionnaires, the researchers concluded that many of the students have heard of radiation and know some specific types, such as X-rays, but their knowledge was not so deep. For instance, they were unaware of the difference between ionizing and non-ionizing radiation, and they did not know much about the radiation sources.

In comparison with the work from Rego and Peralta (2006) and Gutiérrez et al. (2000), there was a greater concern with the conceptions about radioactivity and the atomic structure. Their survey was carried out with 395 students between 16 and 18 years of age, from different regions of Spain, using a questionnaire of elven multiple-choice questions, which allowed for more than one answer. In their study, their students'

responses were analyzed both qualitatively and quantitatively. This way, the authors were able to conclude, mainly, that there was a relationship between the students' conceptions, what was broadcast by the media and what was passed on for generations culturally. This characteristic may be one of the causes of the negative conceptions about radiation that the students had, since less than half a century before this research, Spain was marked by the loss of four atomic bombs by the USA in its territory, which may have caused a certain amount of fear that has been passed on to other generations.

Considering this influence of the media, Acar-Sesen and Ince (2010) pointed out that the internet is also one of the factors that contribute to alternative conceptions, since students, when using the internet as an academic research tool, are not aware that many sources make incorrect information available, and they replicate it. The authors showed the need for an investigation given that studies have shown that the internet, since the late 1990s, has been growing as a place for research, especially among students. From that, Acar-Sesen and Ince (2010) carried out a study using 567 pre-service science teachers. Their study was divided into two stages. The first stage aimed to learn a little more about the way students use the internet for academic purposes. Then, the teachers in training were asked to answer a questionnaire so that the authors could identify, in which keywords were most used if they were to research on the topic "Radiation and Radioactivity." In the second stage, using the most indicated keywords by the students and the most common search tool, the authors analyzed the links of the first 200 pages of Google, to verify the alternative conceptions likely to be present in such sites. It was concluded at the end of the work that on the internet, there was a lot of information written by people without specialization in the area, and that this information was replicated on different sites. Therefore, it would be up to teachers to guide their students in their research.

Considering an increase in the popularity of the radioactivity theme due to the accident at the Fukushima nuclear power plant, Pilakouta (2011) sought to investigate the concepts of Greek engineering undergraduate students about nuclear energy and its applications. For this, an online questionnaire was carried out containing eight multiple-choice questions, whose answers were classified as right and wrong, in addition to serving to identify some alternative conceptions. Similar to that observed by Neumann and Hopf (2012), a large part of the students believed that the highest percentage of radiation, to which man is exposed, originates from electronic equipment such as those used in hospital examinations, while a small portion considers natural radiation. As for the question of nuclear power plants, most of the students did not know how to correctly answer, in which elements are dispersed in the environment in cases of accidents at these plants. Considering these disasters, most students are unaware that only a small percentage of deaths due to the accident in Chernobyl are directly related to radiation contamination. In any case, the students do not seem to be very afraid of nuclear energy and its potential problems, and they have increased their interest in the subject.

Within this controversial context about nuclear power plants and atomic bombs, Maharaj-Sharma (2011) carried out an investigation with the objective of analyzing the way that the feelings of the students, on the nuclear energy theme, influence in their learning process, besides investigating the relation between the lack of information and the sensation of fear. For this, the Indian researcher and teacher used a sample of 50 students, between 17 and 22 years old, from Trinidad and Tobago in the Caribbean. To carry out the research, students were divided into two equal groups, those initiated scientifically and those not initiated scientifically; the former attended physics in their final year of high school, while the rest did not. Each group participated in the research separately. Initially, an interview was conducted with the students not initiated scientifically and a questionnaire was applied to the initiated scientifi ally ones, to verify their conceptions regarding the nuclear energy theme. Maharaj-Sharma (2011) reported that, often, the alternative conceptions in these themes were very much linked to feelings such as concern, panic, or fear, making it difficult to change conceptions already established.

On radioactivity, Dos Santos (2015) showed an analysis of alternative conceptions of students, through a study carried out with approximately 25 students in their 2nd year of high school, in the integrated technical modality of informatics, from the Federal Institute of Bahia, Brazil. Inserted in a Study Situation (SE), with a focus on discussing the topic of radioactivity, health, and energy production, the author applied a questionnaire with three open questions about radioactivity to bring up the conceptions about what students understood by radioactivity and how they "saw" it in society. An interesting observation was the way, in which undergraduate students decided to approach the theme. A great concern with the social context of radiation was noted in the SE described by the author, considering historical issues, such as the Marie and Pierre Curie couple in addition to socio-political ones, promoting a discussion about the possibility of building a nuclear power plant in the city. In any case, the author stated, after the analysis, that in general, the students' conceptions were linked to a pejorative view of radioactivity and radiation, a view directly linked to discussions made by the media on the subject, both in newspapers, as well as in fiction films aimed at entertainment.

In another context, Cardoso et al. (2020) carried out an investigation regarding the students' conceptions about nuclear physics. Their work was carried out with 34 students in their 3rd year of the integrated technical course of a public school in Brazil. This investigation focused on evaluating students' understanding of the atomic structure together with the idea of radiation and radioactivity. For this, the authors used a questionnaire made up of six open questions. In general, the students who participated in this research showed some

knowledge about the theme. Much of the class mentioned nuclear fission and fusion when asked about the possibility of splitting an atom or generating energy through it. In this work, however, an analysis of the degree of knowledge of students on the subject is not made; therefore, it was only possible to conclude that students had already had some contact with the subject. In any case, as the authors point out, this result indicates the students' great interest in the theme, since it is not a topic discussed in the classroom, but relatively well known. Still, it is necessary to mention that there were responses that reinforced the idea of an indivisible atom as well as frequent association of nuclear energy with bombs, factors that also deserve attention.

These works show a certain degree of conformity among basic level students from different parts of the world, indicating that it is a general problem, and not a deficit of certain students or a specific region. In general, there is a certain superficiality in the students' knowledge, which makes it difficult to understand the concept of radiation and radioactivity. In addition, it is noted that in many cases, radiation is linked to negative ideas, sometimes related to a feeling of fear. Thus, the need to promote interventions is evident, to better discuss the concepts of radiation and radioactivity in the classroom.

INTERVENTION PROPOSALS

In addition to recognizing the obstacles in teaching the theme, and verifying a deficit in student learning, it is necessary to propose interventions that aim to overcome this scenario. In this sense, the alternative conceptions are important, contrasting the wrong ideas with scientific knowledge. Thus, the existence of these conceptions can be used in the determination of learning demands, the starting point of the elaboration of a didactic sequence. In addition, to the verification of prior knowledge brought into the classroom, this type of investigation can be used after the interventions to evaluate changes in students' thinking.

In this sense, after the diagnosis of the alternative conceptions, Maharaj-Sharma (2011) proposed an intervention followed by verification of the change in the students' feelings regarding radioactivity. Thus, a week after the first stage, the students were invited to watch a 60-min video and later participated in a seminar on nuclear power generation and the dangers related to this process. Comparing the feelings before and after the intervention, the author concluded that the not initiated scientifi ally showed fewer negative feelings about the subject, while the initiated scientifically remained partially resistant to the construction of a nuclear power plant. Maharaj-Sharma (2011) justified this behavior by the initiated scientificall by the fact that they had been more exposed to the concept of nuclear energy and possibly had been more exposed to a greater number of negative views on this topic.

Similarly, Han et al. (2014) proposed an analysis of the effects of a field study on the perception of 3399 South Korean students in relation to radiation. Initially, students were asked about their perceptions, knowledge, attitudes, and behaviors in relation to the use of radiation in different contexts, comparing their views against a scale of agreement containing the situations proposed by the researchers. Later, activities were carried out to discuss the topic with students. At this stage, activities were initially carried out with a theoretical focus, consisting of a 10-min video and a 45-min lesson, with the aim of presenting applications of radiation in everyday life. Then, an activity was developed with a practical focus, which consisted of measuring the radiation present in different locations of the school. Thus, to ascertain the effects of the intervention, the students were submitted to the same questionnaire presented at the beginning of the investigation. The results showed a positive response to the dynamics proposed by the researchers. It was possible to identify that after the activities were carried out, in general, the students expanded their knowledge about radiation and its applications, as well as decreased their negative perception regarding the theme. However, it was possible to perceive that, in this work, there was greater resistance from the students regarding the need or safety in the use of nuclear plants to produce energy, a fact that would be related to the memories of the Fukushima disaster. In contrast, the use of radiation in medicine presented itself as a more accepted and more necessary theme, according to the students' responses.

Still on the perceptions regarding the use of radiation in different contexts, Tsubokura et al. (2018) evaluated responses from 717 Japanese students, after a sequence of classes on the theme. The work was carried out in three schools in the Fukushima region, all less than 50 km away from the Fukushima nuclear plant, so that, due to their location, the schools that were part of the work had their classes suspended for a few months after the disaster occurred in 2011. The intervention proposed by the authors consisted of a class (~ 60 min) whose objective was to discuss three points: Scientifi knowledge about radiation, the results of monitoring radiation in the region after the disaster at the nuclear plant, and precautionary measures with a focus on radiological protection. This activity was accompanied by a questionnaire, before and after it was carried out, to ascertain the change in the students' behavior in relation to the topic addressed. This investigation allowed the authors to compare students' anxiety level before and after having contact with the scientific discourse on radiation and radioactivity. In general, it was possible to notice that the students became more aware of radiation so that a good part of the students who were initially indifferent to the topic started to recognize the importance of the subject and the dangers in relation to radioactivity. Likewise, students who had a low level of anxiety about the topic demonstrated to have acquired more knowledge and to have more balanced feelings regarding the use of radiation in different contexts. However, in a manner similar to that identified by Maharaj-Sharma (2011), students who already had strong feelings about radiation, in large part, did not show changes in their thinking.

Recognizing the importance of a STS approach in the treatment of radioactivity in the classroom, Santana and dos Reis (2018)

proposed a discussion on food irradiation. The research was carried out with 34 students in their past year of high school, from a public school in Maringá – Brazil. A previous investigation about the students' initial conceptions showed that many had a negative view regarding the use of radiation in general, and a lot of resistance to food irradiation. Based on the initial investigations, the authors proposed a sequence of five classes aimed at presenting scientific knowledge about radiation and reflecting the social factors related to the applications of radiation in the industry. Thus, through readings and debates, the use of radiation in the food industry was initially discussed, which allowed students to better understand the technique and differentiate irradiation from radiological contamination. Later, through the cooperative learning method, students discussed the differences between ionizing and non-ionizing radiation. At another time, the authors developed a discussion, based on texts and videos, about the various applications of radiation and its social implications. This activity developed a more critical view on the theme in students, showing the socio-political responsibility of scientific production. At the end of the activities, to synthesize the discussions, the students were instructed to elaborate concept maps. In these maps, however, it was possible to notice the predominance of technical and conceptual terms, with little mention of the social character of science, an issue addressed during classes.

Alternatively, De Vasconcelos and Leão (2012) proposed the use of audiovisual resources in teaching students about radioactivity. The work carried out with 25 students from a private school in Recife – Brazil, it was based on the theory of cognitive flexibilit , linked to FlexQuest. The computational tool is a variation of WebQuest, based on guided research, encouraging collaborative work, and problem solving. The FlexQuest Radioactivity, developed by the authors, aimed at approaching the theme "radiation" through real situations and audiovisual resources. Thus, initially the students were introduced to three cases, in which radiation was inserted both in a positive context (in the irradiation of food) and in a negative context (in environmental and sanitary disasters). Subsequently, the students had to perform three tasks: Answer a questionnaire about radiation in different contexts, based on the sources made available by the teacher, and relate the three cases discussed initially with an episode of the animated series *Simpsons*, in which Homer uses polonium in a tomato plantation, in groups, develop, and present work to raise investments for the development of a hypothetical city. According to the authors, the results of this intervention were positive, expanding students' scientific knowledge on the subject, encouraging a critical analysis of the use of radiation in the food industry, in addition to developing their argumentative skills.

Reflecting on the importance of stimulating students' interest in learning about radiation and radioactivity, Elbanowska-Ciemuchowska and Giembicka (2011) presented some methods to broach the subject with high school students. The authors' first suggestion was to use experiments. In this case, experimentation in physics is seen as an important tool in science teaching, working on issues such as organization, responsibility, observation, and measurement. In this sense, the authors suggested the measurement of the amount of radon present in the air in different locations of the school, similarly to the activity performed by Han et al. (2014). In addition to this activity, the work from Silva et al. (2017) is worth mentioning, in which the construction of a low-cost Geiger counter was proposed, aiming at applications in the basic school. In addition to experimentation, Elbanowska-Ciemuchowska and Giembicka (2011) suggested the use of discussions among students, to refl ct on exciting topics related to radiation. These discussions could take various forms, such as group discussions, or presentations, as long as they offer the opportunity for students to oppose ideas. Another possibility was the development of projects and activities, in which the student would be responsible for researching a topic of their choice (within the context of radiation and radioactivity) and producing a final work to be presented to the public. Alternatively, the authors also mentioned the use of portfolios, which aggregate the materials researched by the student. In addition, it was also suggested the use of educational games and excursions, such as visits to nuclear reactors. However, the authors make it clear that one method does not exclude the other so that they can be worked together.

In this sense, using multiple didactic resources, Cardoso et al. (2016) carried out a work with students from the Integrated Technical Course in Industrial Mechanics, Rio de Janeiro – Brazil. The proposal of the intervention was to approach the radiation theme through an STS view, developing investigative activities to understand the theme and its applications in the industry. For that, the activities were divided into four blocks. At first, the students watched a documentary about the 1987 radiological accident in Goiania – Brazil. In addition to being used as a motivating agent, to stimulate students' interest in the subject, the documentary served as the basis for a round table held together with teachers of sociology, biology, and chemistry, to discuss the environmental, social, political, and economic aspects of the accident. In the second block, investigative activities composed of experiments and research were proposed to identify objects that emit radiation using a Geiger meter; relate the concentration of drugs to decrease these substances in the body, differentiating the concepts of half-life in biology and physics; and research and discuss the idea of quality and the use of radiation in the industry. The third block consisted of two technical visits to a company that uses radiation to control the quality of its products, and to the nuclear power matrix in Angra dos Reis – Brazil. This activity aimed at allowing students to have real contact with the applications of radiation and the daily lives of people who work in these environments. Finally, in the fourth moment of the intervention, an expository class was proposed, to discuss the applications of radiation, focusing on the use of quality control in various sectors of the industry.

A great concern is perceived in these works, namely, the presenting of the uses of radiation in the different contexts of

industry and health, a fact that may be related to a negative view and, in some cases, to the fear present in some students. Thus, the interventions end up extrapolating from the technical discussion of the content to a more social approach, aiming at the formation of a critical student. In any case, the interventions show a plethora of resources that can be used in the classroom, such as experiments, audiovisual resources, excursions, and debates.

FINAL CONSIDERATIONS

One of the important points highlighted in this literature review is the need to refl ct on how radiation is seen by society, especially by those who do not belong to the scientific community. In this case, the main source of information ends up being the media, in its various modalities. The media, in a way, reflects a common thought, while interfering with this common thought. The investigations presented in this work regarding the way, in which the media presents the idea of radiation and radioactivity demonstrate a certain superficialit in the discussion of the theme and reflects the feeling of fear held by some people, as a result of the radiological disasters that have occurred in the last decades. The presence of radiation and radioactivity topics in different contexts indicates how important it is that they are also present in the high school curriculum. Nowadays, modern physics themes are present on the curriculum of different countries and, in general, present topics on radiation and radioactivity. However, the approaches usually consist of a linear and historical organization that overlooks the connections with nature of science topics. Thus, it is necessary to promote further investigations on what t to do to overcome these challenges.

The alternative conception of students presents itself as a common concern for the analyzed works, acknowledging the importance in the teaching, and learning process of physics. In general, the conceptions identified are repeated in different works, from different regions of the world. Thus, it is clear that the presence of these conceptions is not directly related to a slow or poor education. In fact, these non-scientifi conceptions are common at certain ages and stages of learning and are not necessarily a problem. However, when a wrong view of some fact is not opposed to the scientific explanation, the student loses the opportunity to question and reformulate their previous conceptions, making it a long-term problem. It is in this context that there is a discussion of the promotion of activities related to radiation and radioactivity. It is noticed that in addition to the little knowledge on the subject, there is, in some cases, the feeling of fear regarding the theme, which is characterized as an important issue in the elaboration of an intervention in the classroom.

Thus, this work was also aimed at presenting some proposals for intervention in the classroom, in accordance with the results of the experiences of researchers in the area. In the articles presented, there is a concern with checking the students' thoughts before carrying out any activity. However, it is necessary to mention that in these cases, the importance of obtaining the students' conceptions in the elaboration of an activity may not have been highlighted well enough. The proposed questionnaires have, as their main objective, the assessment of the change in the student's view on the subject worked. As a result, it is possible to notice coherence between the intervention proposals and the main alternative conceptions evidenced in this review. Thus, a great concern in relation to the negative view that students have on radiation and radioactivity is noted. There are several proposals that seek not only to reflect on the dangers and precautions on the subject but also on the benefici l use of these phenomena in contemporary society. Therefore, the proposed interventions, even if implicitly, concern the STS characteristic of physics education, devoting themselves to discussing socio-political and economic issues related to the theme.

CONCLUSION

In this literature review, it is possible to better understand the current scenario of radiation physics and radioactivity in basic education. It is interesting to note that in this work, it was possible to find scientific documents from different countries indicating that the concern with the teaching of this topic is not a local issue. In addition, the amount of work carried out in the past 10 years is noteworthy, a fact that may be related to the disaster in Fukushima in 2011.

Thus, this literature review can be used not only to present the current scenario of discussion about radiation and radioactivity in the classroom but can also be used by educators in their own plans of action as a teacher, giving direction to their research to promote the discussion on these topics.

ETHICS STATEMENT

The authors declare that a statement from the Ethics Committee was not required.

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