PARTICLE PHYSICS IN HIGH SCHOOL: A LOOK AT TEACHING MATERIALS

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INTRODUCTION

Physics is a science that permeates everyday life. With the technological growth and the greater availability of resources resulting from this advance, there is a need to develop work related to the insertion of the study of modern and contemporary Physics in high school. These contents aim to promote the understanding of the universe, allowing the student to perceive and understand the natural and technological phenomena around them.

The study of particle physics provides a view of the microscopic universe. In the quest to understand nature, this science contributes significantly by emphasizing the possible gaps that exist in classical physics. Particle physics is directly linked to atomic models, which are addressed in the disciplines of Physics and Chemistry. The knowledge acquired through this study can be applied in several areas, such as computing, nanotechnology, nanoscience, medicine and biotechnology.

Several factors can contribute to the absence of an approach to these contents in high school, such as the lack of themes in the didactic and methodological materials and the lack of curricular updating (MOREIRA, 2009; SEE; PIETROCOLA, 2006). Therefore, it is important to analyze the approach of Particle Physics, which can help teachers and students in advancing the understanding of nature.

The contents of Modern Physics and Particle Physics are often covered in the 3rd year textbooks, being the last to be presented. For this reason, they may not be seen due to time constraints (NETO, 2020), which makes it necessary to renew their curricula (SIQUEIRA; PIETROCOLA, 2006). It is essential to analyze the importance of the study of particle physics in high school, as well as the way it is approached, reviewing the didactic materials available for the insertion of this content (TEIXEIRA; GODOY, 2021).

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One of the ways to make particle physics classes more interactive and fun for students is through the use of didactic games (SOUZA et. al., 2019; SILVA, 2019; OLIVEIRA and SIQUEIRA, 2018). This proposes ways of inserting available teaching materials, which can be applied in conjunction with the teaching of classical Physics, as in the content of electrostatics.

Given the constant evolution of studies on the phenomena of nature, it is essential to understand physics in a contemporary context. This work aims to analyze the approach of particle physics in the didactic materials used in high school, evaluating its effectiveness and adequacy for student learning.

For this, a review of the existing literature on particle physics and its relevance in the high school curriculum will be made. In addition, educational games that address particle physics are analyzed, evaluating their potential as teaching tools.

With these analyses, it is intended to identify gaps in teaching materials and propose recommendations to improve the inclusion of particle physics in high school. This approach aims not only to enrich students' knowledge but also to better prepare students for the contemporary challenges of science.

The next section deals with the theoretical framework on Particle Physics, its approach in high school and its resources.

PARTICLE PHYSICS

The study of the subject was present in past centuries, and, throughout the studies, much information about its formation was revealed. With this, it was possible to obtain more concrete knowledge on the subject, although it is still evolving. However, this does not diminish the depth of the information already acquired. As in science and scientific research, which are constantly changing, with additions or revisions to already established theories, in the area of physics it was no different. There has always been something to be modified or complemented, in order to provide sufficient information for the understanding of the various phenomena observed in the world and in our daily lives (Costa; Batista, 2017; Popper, 2004).

In particle physics, this process was not different. To arrive at the current knowledge about the elementary constituents of particles, their interactions and the radiations they emit, many discoveries and investigations over time were necessary.

The beginning of the study of particles, that is, of the small constituents of matter, dates back to 460 B.C., when the ancient Greeks began to investigate how things were composed. The first to propose this idea was Democritus, whose perspective was based on philosophical notions. He came to the conclusion that the world was made up of elementary entities, which could not be divided, and called them atoms (Begalli, Caruso, and Predazzi, 2011).

To understand the constitution of matter, today correlated to the concept of the atom, it is essential to consider the contributions of philosophers and thinkers throughout history. Until the sixteenth century, the Aristotelians adopted the theory of small pieces, which aligned with the idea of the atom proposed by Democritus. However, from the seventeenth century onwards, the anti-Christian materialist ideas that emerged during this period led to the rejection of Democritus' atomism (Porto, 2013).

In the Middle Ages, the theory of minimums emerged, which brought new perspectives for philosophical and, consequently, physical development, since this concept is linked to the form of being in the Aristotelian sense. Thus, the idea of atomism was revived, resulting in the recovery of Democritus' theory of the atom.

The trajectory of particle physics is indeed immense, and there have been many scholars regarding the composition of matter. In this context, the evolution of scientific knowledge about the structure of matter and its elementary particles will be discussed, according to the development of the Standard Model established today. This discussion will be brief, not considering the many works that, although they have contributed in a relevant way, have not reached the most recent theories.

It is important to note that the history of the particles that make up the atom is relatively recent. However, there was a process of development, and atomic theory was emphasized from the seventeenth century onwards by chemists such as Lavoisier (1743-1794), Proust (1754-1826) and Avogadro (1776-1856). This theory was consolidated with John Dalton (1766-1844), who described chemical elements as sets of atoms, considering them as constituents of matter, with a massive structure, indivisible and indestructible.

In the search for understanding the composition of matter, the so-called classical period (1897-1932) presents one of the simplest models. Starting with the contributions of J.J. Thomson (1856-1940), who affirmed the existence of an electric charge in the atom from his experiment with the cathode ray tube, he determined the characteristics of the electron, which is the negative particle constitutive of atoms.

Next, Ernest Rutherford (1871-1937) updated the theory through the alpha particle scattering experiment, in which he assumed the existence of the atomic nucleus. He defined that the atom contains two regions: a nucleus and an electrosphere. The nucleus is made up of positively charged particles, called protons, and in order to maintain a neutral electric charge, the number of protons must be equal to that of electrons (GRIFFITHS and DAVID, 2018).

Soon after, Niels Bohr (1885-1962) solved the limitations of Rutherford's model, proposing the existence of electron shells in the electrosphere (Rutherford-Bohr model) and suggesting that electrons move around the nucleus in a quantized way, thus maintaining their stability (Bohr, 1913). Finally, James Chadwick (1891-1974) proved the existence of the neutron through the observation of the helium atom, which has twice as many protons as hydrogen, but four times its mass, indicating the presence of another type of particle in the nucleus, devoid of electric charge (Chadwick, 1932).

The confirmation that the atom is made up of a nucleus composed of protons and neutrons, with electrons orbiting around the nucleus in a quantized motion to maintain stability, occurred in 1932. However, the studies did not stop there, as there was still much to be understood. According to the principle of action and repulsion, electric charges of the same sign repel each other, while charges of opposite signs attract each other. The question then arises: how do protons, which have a positive charge, and neutrons, which have no charge, in the nucleus not undergo electrostatic repulsion? This question motivated the emergence of more research in search of understanding.

One of the characteristics of particle physics began with the study and interpretation of the electromagnetic field from its quanta. In an attempt to solve the problem of the emission of electromagnetic radiation by the black body, the concept of photon emerged, proposed by Max Planck (1858-1947) as an emission mechanism in which the electromagnetic field is quantized, and the quanta of this field is the photon. On the other hand, Albert Einstein (1879-1955), through his studies on the photoelectric effect, concluded that quantization is not a characteristic of the emission mechanism, but rather an intrinsic property of the electromagnetic field. In his investigations into the interaction of radiation with matter, Arthur Compton (1892-1962) perceived a transfer of momentum, thus proving the corpuscular character of light. These findings led to the understanding that electromagnetic interaction occurs through its mediator particle, the photon (GRIFFITHS and DAVID, 2018).

With the works of Hideki Yukawa (1907-1981), Carl D. Anderson (1905-1991), Clyde Cowan (1919-1974) and César Lattes (1924-2005), it was possible to obtain a more complete model of the constitution of matter. Initially, Yukawa proposed a theory about the force that keeps protons and neutrons inside the nucleus, called the nuclear force. This force must be quantized, it is stronger than the electromagnetic force, and it has a very short range. For this, the mediating particle had to be massive; Thus, he suggested the existence of a particle that could be emitted and absorbed by protons and neutrons, whose interaction would generate an attraction, calling it a meson, because it has a mass intermediate between that of the proton and that of the electron. (MOREIRA, 2007).

After that, Carl D. Anderson and Seth Neddermeyer discovered the muon (mi meson), an intermediate-mass particle present in cosmic rays, with a longer lifetime and smaller mass than expected, resembling the electron. Its interaction with the atomic nucleus was very weak, indicating that it could not be the quanta of the nuclear force. In addition, César Lattes carried out an experiment that led to the discovery of another particle that disintegrated in the upper layers of the atmosphere, decaying into a muon. This particle was called a pion (pi meson) and had characteristics of the meson. Later, it was found that the pion had a strong interaction with the atomic nucleus, thus meeting the characteristics described by Yukawa for the stability of the nucleus. Therefore, it was recorded that the person responsible for the nuclear force that keeps protons and neutrons together is the pion, which has a short range of force, despite being massive (MOREIRA, 2007).

With the advance in the search for knowledge about the composition of matter, the discovery of antimatter emerged. This process began with Paul Dirac (1902-1984), who, in his studies, formulated an equation that reconciled quantum theory with special relativity, addressing the behavior of an electron in motion at relativistic speeds. However, the equation presented a problem in providing two possible solutions: one corresponded to the electron with negative energy and the other to positive energy (positron). Dirac interpreted this situation as indicating the existence of an antiparticle for each particle. (DIRAC, 1981).

On the other hand, the experimental evidence of the positron was verified by Anderson (1905-1991), who observed the trail left in the bubble chamber, noting a difference in the radius of curvature. In his analysis of the applied fields and trajectory, he came to the conclusion that the characteristics of the particle were similar to those of the electron, but with a positive charge. Later, the existence of the antiproton and the antineutron were evidenced, which were detected in a particle accelerator known as Bevatron. (ANDERSON, 1933).

By observing beta decay, it was found that the energy of the emitted electron, called the beta particle, was variable. Thus, Wolfgang Pauli (1900-1958) proposed the existence of a new particle produced in decay, without electric charge and very light, which he called a neutrino, later identified as an antineutrino. It turned out that this particle also explains the decay of the muon into a pion, making a 90° angle in its trajectory. In search of experimental evidence of the neutrino, Clyde Cowan (1919-1974) and Frederick Reines (1918-1998) tried to identify it through a nuclear reactor, investigating the possibility of an inverse beta decay occurring, which led to the confirmation of the existence and basic properties of this particle. Raymond Davis (1914-2006) and his team, by indicating that reactions involving neutrinos do not occur with antineutrinos, proposed the existence of the antineutrino. Finally, in 1962, Leon Lederman, Melvin Schwartz, Jack Steinberger and their collaborators suggested the hypothesis of the existence of two types of neutrinos. (GRIFFITHS and DAVID, 2018).

With the discoveries of the electron, muon and neutrinos, as well as their antiparticles, the lepton family was formed. Next, Konopinski and Mahmoud proposed a new conservation law, of the lepton number, which is a conserved quantum number, responsible for representing the number of leptons and antileptons in a reaction. It is worth noting that leptons are particles that are not subject to strong interaction. (GRIFFITHS, 2008).

From then on, particle physics seemed complete in allowing the description of the composition of the universe, including the structure of the atom, neutrinos, and antiparticles. However, many other particles emerged after 1930. Gell-Mann and Nishima proposed a new law of conservation, called weirdness, due to the fact that these particles are created quickly and decay slowly. Thus, these particles were termed "strange," indicating that the production process was distinct from the decay process. In other words, the processes that occur by the interaction of the strong nuclear force retain the strangeness, while those that occur by the weak nuclear force do not. (GELL-MANN, 1982).

In addition, it was found that there were particles that combined to form protons and neutrons. Gell-Mann called these particles quarks, and the ones he predicted were up, down, and strange. Subsequently, the fourth quark, called charm, was discovered by Bjorken and Glashow, while the fifth quark, bottom, and the sixth quark, top, were also identified by Glashow. Quarks are very small subatomic particles and are differentiated by their charge and mass. Each quark has its own antiquark. The combination of quarks for particle formation is divided into hadrons, which are composed of three quarks, and mesons, which are formed by one quark and one antiquark. (MOREIRA, 2007).

In addition, Glashow, Weinberg and Salam, in 1983, proposed the electroweak theory, which predicts three vector bosons: two charged and one neutral, as mediators of the weak force.

What is currently known as the standard model has gone through this entire trajectory so that the theory of elementary particles is organized into their respective families and interactions, mediated by mediating particles (MOREIRA, 2009). However, it is not yet a complete theory, as questions remain to be answered, such as the different mass values of elementary particles and the lack of consideration of gravitational phenomena. However, it can be concluded that the universe is made up of six leptons, six quarks, mediator bosons and their antiparticles.

THE IMPORTANCE OF THE PARTICLE PHYSICS APPROACH IN HIGH SCHOOL

With the growth of the technological world and the greater access to resources arising from this advance, there is a need to develop work related to the insertion of the study of modern and contemporary physics in high school, that is, to teach the contents of post-Newton physics. These contents are essential for understanding the universe created by the current world, allowing the student to perceive and lead with natural and technological phenomena present in everyday life, in addition to understanding the distant universe, based on the laws, principles and models built by physics (SIQUEIRA; PIETROCOLA, 2006).

In everyday life, the phenomena of modern physics are present in technologies such as the operation of cell phones, X-rays and ultrasounds. Behind these innovations, there is knowledge built and shared over recent history, which is of paramount importance in high school. According to Gomes, Garcia and Calheiro (2015), high school is the ideal time to stimulate critical and reflective development, bringing questions that allow students to perceive the current problems of the world. In this context, scientific knowledge plays a key role in helping students develop a critical perception of their surroundings. The study of particle physics, in particular, has contributed to the resolution of problems in several areas, with medicine, nanotechnology and biotechnology being some prime examples.

It is essential that people know the current atomic model, since the search for understanding the constitution of things in the world is a constant concern. The lack of approach to recent physics content prevents individuals from updating themselves, leading them to know only old models and theories. This makes them unaware of the latest updates and discoveries, which can shed light on previously ununderstood issues. In many areas of science, theories are initially presented as proposals, and after extensive studies, they are confirmed, in addition to being enriched by new discoveries related to the subject. Therefore, it is essential to integrate this updated content into teaching so that students understand the current state of scientific knowledge.

It is not a matter of detracting from ancient approaches, but of understanding the current context and comparing previous knowledge with contemporary knowledge, thus showing the development of theories over time. This combination of contents can benefit learning, as in the case of the study of the atomic model, which is introduced at the beginning of chemistry teaching. The students already have a notion of the atomic structure, but when they reach the third year, in the electrostatics part, the most recent models that explain complex phenomena are not presented. An example of this is the issue of electrostatic repulsion in the atomic nucleus. Despite being composed of protons, which have equal charges and therefore repel each other, the nucleus does not disintegrate due to the nuclear force, an interaction that is not sufficiently addressed in the curricula. Knowing the current atomic model is fundamental, and this need extends to all the contents of physics that have been updated and that are an integral part of modern physics.

The insertion of modern physics contents has been a widely discussed topic for a long time, highlighting both the relevance of its approach and the works that contribute to teaching-learning, including proposals and planning. Several studies support the inclusion of these contents in high school for several reasons (OSTERMANN; FERREIRA; CAVALCANTI, 1998; OLIVE TREE; VIANNA; GERBASSI, 2007; FERREIRA, 2013; FILE; OSTERMANN; CAVALCANTI, 2017; SILVA; EIFLER, 2019; GOMES; DUARTE; SANTOS, 2019; DE SOUZA; FERREIRA, 2020).

According to Dorsch and Guio (2021), particle physics topics are the most recommended among modern physics content by 54 physicists, 22 high school physics teachers, and 22 researchers in physics education interviewed by Ostermann and Moreira (2000). The inclusion of these topics in high school is important, as it shows that science is a process in constant improvement and still in development. This search for the insertion of modern physics and particle physics aims to promote learning that makes students more participative, critical and aware of the world around them.

In a study based on the Notebook of Learning Expectations of the state of Paraná, which addresses the implementation of the Guiding Curricula of Basic Education, Costa and Batista (2017) identified that the contents of particle physics, such as the nature of matter, elementary particles, the standard model and fundamental interactions, are among the topics that meet these expectations.

Therefore, it is essential to address the contents of modern physics in high school, allowing students to learn about the most recent discoveries in the area. This approach helps to understand the context, the advances, and the contributions that these discoveries have brought to today's world.

THE APPROACH TO PARTICLE PHYSICS AND ITS RESOURCES

Physics is often considered uninteresting, but its mathematical language is fundamental to understanding everyday phenomena (PIETROCOLA, 2002). To modify this perception, Costa and Batista (2017) emphasize the importance of presenting physics as a human and collaborative activity, promoting greater approximation of students with science.

Faced with the negative view of the discipline, many studies seek to present content in a creative way. Today, with easy access to information, several innovative approaches can be found online, stimulating creativity in teaching. Such initiatives aim to transform the reality in which physics has found itself, making it more attractive and accessible.

The use of technologies, such as computer simulations and educational games, can be an effective strategy to facilitate the understanding of complex concepts. Ferreira et al. (2020) state that "games and simulations promote a dynamic learning environment, stimulating students' curiosity and engagement". These tools not only make learning more interesting but also allow students to experiment with theories in a controlled environment.

In particle physics, the scarcity of approach to this content in high school has led many researchers to highlight it in their investigations. In addition to recognizing the importance of addressing this topic, there was a concern with the strategies used to do so effectively.

Particle physics, in particular, needs a more in-depth approach in high school, leading researchers to investigate effective ways to treat it. The creation of didactic strategies that make the content accessible is essential, since the complexity of its theories often makes it inaccessible to students. In addition, the inclusion of topics on particle physics in teaching materials and specialized books is crucial. Studies by Souza and Lima (2019) indicate that "teacher training and the quality of available materials are determining factors for the approach to particle physics in high school". This demonstrates the need for continuous investment in teacher training and in updating educational resources.

In summary, the approach to particle physics in high school should be rethought and adapted to engage students. The combination of creative methods, educational technologies, textbook reviews, and adequate teacher training can turn this discipline into a fascinating and accessible area.

METHODOLOGY

In order to identify how particle physics is approached in the teaching materials used in high school, a qualitative research was carried out through bibliographic analysis, reviewing in detail the literature on the teaching of particle physics, pedagogical approaches and the use of teaching materials, with a focus on games.

For the investigation, didactic games on particle physics developed by Jesus and Amorim (2019), Souza et. al. (2019) and Neves and Silva (2021).

Didactic games have specific purposes, but they all share the objective of assisting in the teaching and learning of particle physics. One of the selected games is a card game, where students become familiar with elementary particles, the constitution of hadrons, and the conservation of electric charge. The other two consist of board games that require answers to questions about particle physics and the history of science. As students advance through the squares of the board, they get to know elementary particles, their histories, and content related to particle physics. One of the games, in particular, aims to simulate the journey through the Large Hadron Collider (LHC) experiments, culminating in the discovery of the Higgs boson in the ATLAS experiment.

RESULTS AND DISCUSSIONS

In this section, the analysis of the resources of the particle physics theme will be organized into topics, analyzing different educational games and how they represent particle physics, considering the dynamics and the potential to teach complex concepts in a playful and interactive way.

GAME REVIEWS

The games chosen for analysis were of a bibliographic nature and their authors, year of publication and titles will be described in alphabetical order of the name of the games in Chart 1 below:

Table 1 – Authors, year of publication and titles of the games chosen for analysis

AUTHORS	YEAR	SECURITIES
Jesus and Amorim	2019	A Potentially Significant Teaching Unit Proposal to Teach Particle Physics through Card Games
Souza et. Al.	2019	Particle Physics Game: Discovering the Higgs Boson
Neves e Silva	2021	On the Particle Trail: Teaching Particle Physics from a Board Game

Source: Prepared by the authors, 2024.

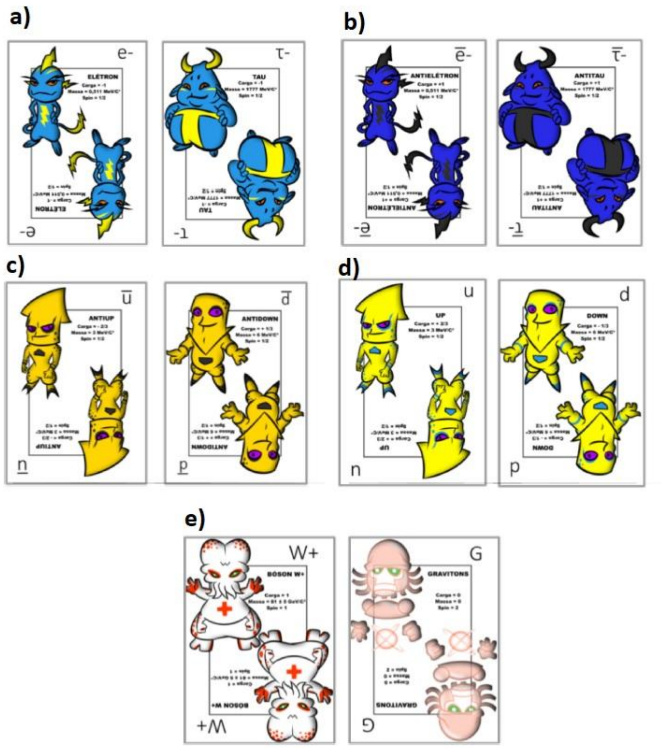
The next subsections detail the games studied.

Dance of quarks and leptons (JESUS AND AMORIM)

The purpose of the work developed by the authors was the production and application of a didactic sequence based on the Potentially Significant Teaching Unit. And in this sequence, a card game was developed and applied whose objective was to analyze the standard model, the physical concepts developed and also to discuss topics related to the formation of hadrons.

The game consists of a deck with a total of thirty-six cards, these being lepton cards, antileptons, quarks, antiquarks and bosons, as shown in Figure 1, also a meson particle die and a baryon particle die. The game can be used for two purposes, the first is to familiarize the student with the families of elementary particles and the second is about the constitution of hadrons and the conservation of electric charge.

Figure 1: Model charts of leptons a), antileptons b), antiquarks c), quarks d) and bosons e).



Source: Jesus and Amorim (2019)

Familiarize the student with the families of elementary particles

For this first purpose, only the thirty-six cards are used and the game rules of the first stage described by the authors are:

- Each student must receive eight cards in each round;
- the first to play is the student who is after the one who dealt the cards;
- in the next round it shuffles the student who started the game in the previous round;
- the student who receives the cards first is the first to pick up a card from the pile and discard the one that does not fit him;
- the next student can take the discarded card or pick one from the pile;

- Each student must form particle/antiparticle pairs, respecting the family of the cards, e.g.: electron/antielectron;
- the student who forms four pairs first wins the round;
- each round is worth one point;
- The student who scores three points first wins the game.

Constitution of hadrons and conservation of electric charge

For the second purpose, the thirty-six cards, one meson particle die and one baryon particle die are used, and the game rules that can also be changed described by the authors are:

- students can play individually or in pairs;
- the teacher throws one die at a time, which can be the meson or baryon die;
- the player must form the drawn particle respecting the conservation of the electric charge;
- The player can consult the table with the quark components of each particle;
- each student must receive nine cards in each round;
- the first to play is the student who is after the one who dealt the cards;
- in the next round, it shuffles the student who started the game in the previous round;
- The student who receives the nine cards first is the first to pick up a card in the pile
- and discard the one that does not serve him;
- the next student can take the discarded card or pick one from the pile;
- the student who first forms the particle drawn on the die wins the round;
- each round is worth one point;
- The student or pair that scores three points first wins.

As the purpose of the game is to familiarize students with the families of elementary particles, the objective is to form pairs of particles and antiparticles, adding four pairs every three rounds. The benefit of this rule is the memorization of the particles by the repetition of the symbols, which can also draw the students' attention to the memorization of the figures.

A suggestion of rules for the game, aiming at familiarizing students with the families of particles, would be the use of card discard as soon as the pairs are formed. In this way, the goal would be to find and discard the largest number of pairs of cards. The game could be played by 2 to 6 students, using a deck of thirty-six cards. The rules of the game would be:

- Shuffle the deck and distribute all the cards face down among the students, so that each one receives an equal number of cards.
- Place the rest of the cards in the center of the table, forming a discard pile with the top card facing up.
- Each student must arrange their cards into individual face-down piles.
- The student to the left of the discard pile starts the game. In turn, the student can perform one of the following actions:

Discard a card: The student takes the top card of his or her individual pile and discards it in the discard pile, face up.

Try to make a pair: The student takes the top card from the discard pile and checks to see if it pairs with any cards in their individual pile. If a pair is formed, the student discards the two cards in the discard pile and scores a point for himself. If they do not make a pair, the student places the discard card on their individual pile, face down.

- Each student makes his move. A student cannot look at the other students' cards.
- If the discard pile runs out, the top card of the draw pile is face-up and the game continues.
- The game ends when all cards are discarded and form pairs, or when a student reaches a predetermined number of points (e.g., 5 points).
- The student with the most points at the end of the game wins.

As for the purpose of the constitution of hadrons and the conservation of electric charge, whose objective is to form the particle drawn on the die, it would be interesting to use this criterion as an evaluation of the content covered in the course. The approach to the content, carried out through games or other methodologies, must be communicated to the students, allowing them to prepare adequately for the assessments. Through the game, students can expose their knowledge individually, with the same drawing stage being carried out, and the score would be equivalent to the number of correct answers in the assembly of the particles drawn with the cards. For example, two particles could be drawn from each die.

Discovering the Higgs boson (SOUZA et. al.)

In his work, the author uses playful and fun strategies to teach the phenomena studied at the Large Hadron Collider, promoting discoveries and building knowledge about the Higgs boson theory and its detection in the ATLAS experiment. For this, a board game called "Discovering the Higgs Boson" was developed, which follows the experiments of the Large Hadron Collider until the discovery of the Higgs boson in the ATLAS experiment.

In the game, students will get to know elementary particles by answering questions and facing obstacles and challenges, such as escaping a black hole, a time loop, or gamma radiation, as well as being confined by the strong nuclear force. In addition to the challenges, players will be able to reduce distances through space-time travel and, with the help of protons and neutrinos, they will be able to advance in the game. To escape the black hole, they will use the decay of the pions, and may even discover the bosons.

The game pieces include a board, a dice, question cards, and four cones of different colors to represent the players or groups of players

To deepen the game's instructions, the author explains, through a hypothetical playthrough, the benefits and challenges it offers. The board contains houses of three types: particles, LHC experiments, and black holes, see Figure 2.

Among the particles, the proton stands out, whose function is to allow the participant to play once again, in addition to presenting a brief explanation of its characteristics and the role of the beams within the LHC. Another important element is the meson, which, in addition to an introduction to its characteristics, has the function of escaping the black hole zone and advancing to the CMS (Content Management System) experiment, taking advantage of the instability of the pion to "hitch a ride" with the muon.

Figure 2: Board model for the game

Source: Souza et. al. (2019)

The photon is also an important particle, with the function of returning two houses before being hit by gamma radiation; The author explains its characteristics in relation to radiation. The quarks, in turn, have the function of making the player go two rounds without playing, also accompanied by an introduction to their characteristics.

The neutrino particle has the function of reversing the game, allowing the player to "hitch a ride" with the neutrino, not interact with anything and advance two squares, in addition to including a brief explanation. Finally, the W^- and Z boson particles, which mediate the weak force, have the function of answering a question to move towards the great discovery of the Higgs boson.

Among the LHC experiments, the LHCb experiment stands out, whose acronym stands for "Large Hadron Collider beauty experiment". Its purpose is to detect violations in symmetry, and its function in the game is to choose a participant to answer a question and wait for their turn to play.

Another experiment is the CMS, whose acronym in Portuguese stands for "Compact Muon Solenoid". Among its objectives are the detection of extra dimensions, the study of collisions between heavy ions and the investigation of physics in the TeV energy range.

The ALICE experiment, whose acronym in Portuguese translates as "A Large Ion Collider Experiment", aims to study plasma and high-energy ions. In the game, your job is to wait for your turn to play and choose a participant to answer a question.

Finally, we have the ATLAS experiment, whose acronym translated into Portuguese means "Toroidal Instrumental Device". This experiment acts as a detector for particles, including the Higgs boson and supersymmetric particles, and its function in the game is to make the player go a round without playing.

The square where the black hole is located has the function of bringing the participant to this situation, making him wait for his turn to play. If the player is successful in the answers, he will be able to escape the gravitational pull and will be able to advance in space-time. If it fails, it will fall into a time loop and return to the beginning of the game.

As the goal is to discover the Higgs boson, when reaching the end, the winning participant will receive the message: "CONGRATULATIONS! YOU HAVE JUST MADE A GREAT DISCOVERY AND REVOLUTIONIZED PHYSICS. FEEL PROUD TO GO DOWN IN THE HISTORY OF SCIENCE.....", AS WELL AS GAIN INFORMATION ABOUT THIS PARTICLE. The author applies the game and, in his work, reports his experiences.

The game basically consists of going through each step of the discovery of the Higgs boson. In a different way, the student can obtain information about the path to this discovery and understand the representation of each surprise square found on the board, according to the square on which it lands, whether it is related to particles, challenges to be completed or to one of the experiments. This means that the student will achieve discovery learning by exploring the rules and challenges of the game. In this way, students build their own knowledge in an active and meaningful way, while also facing situations that stimulate curiosity and critical thinking.

This board game is an excellent tool for teaching-learning, as the competition in search of the finish line, that is, the discovery of the Higgs boson, will provide moments of learning combined with fun, making knowledge a pleasant and memorable experience.

On the trail of particles (NEVES and SILVA)

The game called "on the trail of the particles" was used by Neves and Silva (2021) in his elaboration for a didactic sequence that was based on Vygotsky's theory, as Neves and Silva (2021, p.7) describes "For Vygotsky (1991), didactic games awaken curiosity, initiative, self-confidence in the student, learn to act, in addition to providing the development of language, thought and concentration". Figure 3 shows the board game.

Figure 3: Board Game Model

Source: Neves and Silva (2021).

The game consists of a space trip in which participants search for elementary particles. It includes a board, an electronic dice, four pins, cards with questions about subatomic particles, cards with questions about the history of science, surprise cards, antimatter cards, and cards about forces and particles.

The electronic data is optional, but it was made using an Arduino, seven high-brightness LEDs (red), two 100 Ω resistors, a mini switch switch, wires for the connections and a 9V battery. It was programmed to randomly draw the numbers from 1 to 6. The four pegs are used to go around the board.

In a total of 107 elaborate letters divided into:

- Subatomic Particles Card: In the game, the teams used these cards to access the question if it is on the board on a yellow square. And there are a total of 24 cards with recent questions about particle physics.
- History of Science Cards: In the game, the teams used these cards to gain access to the question if they were on the board on a red square. There are a total of 24 with questions related to the history of science.
- Surprise Cards: In the game, teams used these cards only if it is on the board in a blue-colored square, the surprise cards allow the player to advance or move back squares on the board, or pass their turn to play and are a total of 15 cards.
- Forces and Particles Cards: In the game, these cards have scores and for each question answered correctly in the game, the team gets a "Forces and Particles" card and there are a total of 24 cards.
- Antimatter card: In the game, teams will gain an Antimatter card whenever they get an answer wrong during the game, and there are a total of 24 cards referring to the particles.

And the rules of the game are:

- Before starting a game, the teacher/researcher must choose a student from the class to ask the game questions to each team. The chosen one must read the rules of the game and shuffle all the cards with questions and answers.
- Only two teams can participate in a game and only the leader of each team will move the pin on the board in order to reach the end of the path.
- To start a match, the leaders of each team must roll (odd or even) to know who will first activate the electronic dice. The team that obtains the highest score in the electronic data will be the first to answer the questions.
- If the number drawn on the die corresponds to a square on the red track, the team leader must choose a card from the history of science cards to be answered.
- If the number drawn on the die corresponds to a square on the yellow track, the team leader must choose a card from the subatomic particle cards to be answered.
- If the number drawn on the die corresponds to a square on the blue track, the team leader must choose a card from among the surprise cards.
- If the team gets a question in the game right, they will choose a green card titled "Forces and Particles". If you make a mistake, you must take a purple card called "Antimatter".
- A purple-colored card eliminates a green-colored card.

- The team that finishes the game with the highest number of green cards will receive a bonus.
- The team that first finishes the trail wins the game.

The trajectory taken by this game provides learning in a more motivating way, as the playful nature of board games arouses the interest and curiosity of students. As the game is based on questions and answers, it promotes the development of interpersonal skills, since students need to debate, argue and work as a team to achieve the common goal: the completion of the trail and victory in the game. This process contributes to the development of interpersonal skills that are important for life in society.

The use of prizes is a motivating device that encourages students to commit more to the answers, since a prize will be awarded to the one who manages to accumulate the most cards, that is, who answers the most questions correctly. The bonus designed by the author stimulates concentration to understand the questions, in addition to promoting debate, which also contributes to the learning of the content.

The next section is the completion of the work.

CONCLUSION

It is perceived that particle physics is not adequately discussed, limiting students' understanding of fundamental particles and their interactions. Crucial topics, such as the Standard Model, which describes elementary particles and their forces, are typically not integrated into the content, which could significantly enrich learning.

This gap, highlights the need to update curricula and teaching materials to include particle physics, so that providing students with a solid and contemporary grounding on the subject would not only help consolidate their understanding of science, but also spark interest in emerging areas of physics. Thus, a more comprehensive approach could better prepare students for future challenges and discoveries in science.

The didactic games analyzed demonstrate significant relevance in their approach, as they explore in a concrete way the world of particle physics. These tools are objective and well-structured, conveying a sincere commitment to explaining the topic in an accessible and engaging way.

This approach not only elevates teaching and learning, but also stimulates students' interest in learning and discovering more about the universe and its implications in everyday life. By making particle physics more interactive and playful, educational games can transform the learning experience by encouraging curiosity and scientific inquiry among students.

In view of this, it is crucial to carry out future analyses on the approach to particle physics contents in high school, with the aim of promoting the updating and integration of the themes. This updating is critical to ensure that students have access to relevant and contemporary scientific knowledge. In addition, an integrated approach can facilitate the understanding of interactions between particles and their applications in everyday life, strengthening the overall understanding of physics. Investing in research and discussion on this topic will help shape curricula that better prepare students for the scientific challenges of the future and stimulate their interest in science.

It would be interesting if more work were developed aimed at creating games that teach these contents in an effective and fun way. Educational games can turn learning into an engaging experience, helping students better connect with concepts. Such an initiative could foster collaboration between educators, game designers, and scientists, resulting in innovative tools that make particle physics more accessible and compelling. In this way, learning would not only become informative, but also pleasurable, stimulating students' curiosity and interest in science. This approach can create a more dynamic and interactive learning environment, which is essential for the development of critical and scientific thinking among young people.

Thinking about future work, two objectives stand out. The first would be to continue research on the approach to particle physics in other educational institutions, using textbooks as resources. This would allow for a broader comparison of educational practices. The second objective would be to develop a field research focused on the approach to the theme, collecting information directly from the reality reported by students and professors of a specific institution. This combination of methods would enrich the understanding of the topic and help identify practical solutions to improve education in this field.

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