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ARTICLE

# PRESENTATION OF CONCEPTS IN A CHILDREN'S SCIENCE COMMUNICATION BOOK: THE CASE OF "ISAAC NO MUNDO DAS PARTÍCULAS"

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## ABSTRACT:

This work aims to analyze the scientific ideas and concepts present in the science communication book aimed at the child's public "Isaac in the World of Particles", written by Elika Takimoto. We start from the contributions of historical-cultural psychology on the potential, spontaneous and scientific concepts, seeking to understand the relations and forms of meaning of the scientific ideas presented by the work. Excerpts from the book in which scientific concepts or key ideas were present were selected and analyzed. The unit of analysis was the word. The results indicated that the book mobilizes several meanings and logical-abstract (conceptual) structures to formalize complex elaborations and scientific concepts. The analysis of the concepts: atom, particle and vacuum, indicated strategies for the meaning production, which contemplated: argumentative disputes, contextualization, curiosity, history of science, spontaneous concepts etc.

**Keywords:**
Science communication;
Children's literature;
Scientific concepts.

## *LA PRESENTACIÓN DE CONCEPTOS EN UN LIBRO DE DIVULGACIÓN CIENTÍFICA INFANTIL: EL CASO DE "ISAAC NO MUNDO DAS PARTÍCULAS"*

## RESUMEN:

Este trabajo tuvo como objetivo analizar las ideas y conceptos científicos presentados en el libro de divulgación científica dirigido al público infantil *Isaac no Mundo das Partículas*, escrito por Elika Takimoto. Partimos de las aportaciones de la psicología histórico-cultural sobre los conceptos potenciales, espontáneos y científicos, buscando comprender las relaciones y formas de significado de las ideas científicas presentadas en la obra. Se seleccionaron y analizaron extractos del libro en los que había conceptos científicos o ideas clave. Se consideró la palabra como la unidad de análisis. Los resultados indicaron que el libro moviliza varios significados y estructuras lógico-abstractas (conceptuales) para formalizar elaboraciones más complejas y conceptos científicos. El análisis de los conceptos: átomo, partícula y vacío indicó estrategias para la producción de significado, que contemplaron: la contextualización, la curiosidad, las disputas argumentativas, el uso de conceptos espontáneos, de la historia de la ciencia, etc.

**Palabras clave:**
Divulgación científica;
Literatura infantil;
Conceptos científicos.

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*A APRESENTAÇÃO DE CONCEITOS EM UM LIVRO DE DIVULGAÇÃO CIENTÍFICA INFANTIL: O CASO ISAAC NO MUNDO DAS PARTÍCULAS*

**RESUMO:**

Este trabalho objetiva analisar as ideias e conceitos científicos presentes na obra de divulgação científica voltada para o público infantil "Isaac no Mundo das Partículas", escrita por Elika Takimoto. Partimos das contribuições da psicologia histórico-cultural sobre os conceitos potenciais, espontâneos e científicos, buscando compreender as relações e formas de significação das ideias científicas apresentadas pela obra. Foram selecionados e analisados trechos do livro no qual conceitos científicos ou ideias-chave estavam presentes. A palavra foi considerada a unidade de análise e os resultados indicaram que o livro mobiliza diversas significações e estruturações lógico-abstratas (conceituais) para formalizar elaborações mais complexas e conceitos científicos. A análise dos conceitos: átomo, partícula e vácuo, indicou estratégias para a produção de sentido, que contemplaram a: contextualização, curiosidade, disputas argumentativas, uso de conceitos espontâneos, uso da história da ciência etc.

**Palavras-chave:**
Divulgação Científica;
Literatura Infantil;
Conceitos Científicos.

## INTRODUCTION

Science Communication (SC) is a historically consolidated human activity, which has gained new proportions with mass communication. According to Silva (2006, p. 54), in the 18th century, "European amphitheaters were filled with a public eager to learn about new machines and demonstrations of pneumatic, electrical and mechanical phenomena". In addition to scientific exhibitions and writings, such as events, articles and periodicals, the existence of books written by scientists for a public considered non-specialist or layman is known at the same time (Silva, 2006).

Understanding that SC has a non-specialized audience as a reference does not mean understanding that communications of this type are broad and directed to the population in a non-specific way. The specialized literature has considered for years that SC productions are aimed at certain audiences, which vary according to age group, social class, consumption habits, etc. (Grillo, 2006). Despite this, SC is not always restricted to a small environment of placement and circulation, a fact that promotes the expansion of the profile idealized by the promoter (Lima & Giordan, 2017)

Reis (1982) clarifies that SC is more than the simplification or translation of scientific knowledge for a lay public. For him, SC started to "also reflect the intensity of the social problems implicit in this activity" (p. 77). Lima and Giordan (2021) accentuate the criticism of the interpretation of SC as a discursive re-elaboration and corroborate with Grillo's (2006) positions, showing that it is not produced only by the scientific sphere. SC is the product of an activity inscribed in the interface of different spheres of ideological creation, whose activities performed dispute motives, purposes, rules, agents, cultural tools, among other elements (Lima & Giordan, 2021).

According to Lima and Giordan (2021), the practice of disseminating science should not be understood only as a communicative process that aims to transmit information or messages to subjects who do not have access to them. The practice of disseminating science must be seen as a series of activities, understood as the objectification of praxis, developed in the interactions that occur between the spheres of ideological creation.

SC can be produced in different ways, whether through texts, audios, videos, setting up environments, etc. In this work, we highlight the textual productions that aim to carry out SC activities, more

specifically those aimed at children. These productions can have a large circulation in society, such as the magazines *Ciência Hoje das Crianças*, *Recreio* and *Mundo Estranho*, in addition to many other books, blogs and websites aimed at this audience.

In general, these texts are characterized as expository, informative and argumentative productions, which aim, through journalistic language, to approach knowledge linked to the fields of science and technology (Rosa & Terrazzan, 2002). However, we can also find literary texts that perform this type of activity. Lima, Ramos and Piassi (2020) point out that there is a certain consensus in the establishment of a didactic discourse in CD texts for children.

Another characteristic of SC produced for children is the materialization of abstract concepts, which constitutes a strategy adopted to approach scientific content. The image, comparison, allegory and metaphor can be tools for bringing together what the child knows and the scientific concepts addressed by SC (Ramos, 2014).

Researches carried out with children and young people show that this part of the population has a great ability to interact with scientific culture themes (Massarani, 2007; Bueno, 2012). We add that a significant part of the SC produced for this audience has conceptual errors, scientific contente of low quality or inadequately presented (Massarani, 2005; Oliveira, 2015; Vieira Junior & Almeida, 2021).

When discussing SC for children, it is pertinent to highlight that texts cannot be classified as their own or unique discursive genre. Even with the specification of the public, SC is produced through several discursive genres (Grillo, 2006; Lima & Giordan, 2021). It is possible to find news, letters to the reader, interviews, poetry, comics and many other discursive genres that support the production of SC.

We highlight the literary books as a particularly interesting way to study SC for children, especially because they mobilize playful elements in an explicit way, which seems relevant to reach this audience.

Although the study of SC and its interface with literature is not so frequent in the field, researchers have emphasized that the relationship between Science and Art is beneficial both for education and for science communication. Drigo Filho and Babini (2016) highlight how the work *The divine comedy*, by Dante Alighieri, can contribute to student motivation, the introduction of physical concepts, the construction of models in Physics and in more general aspects, such as the discussion and comparison between contemporary and medieval world views.

For Ferreira and Raboni (2013), literary works that address Science and Technology can represent the reader's first contact with the wide range of scientific concepts and ideas. In addition, Scalfi and Micaldas (2014) point out that the use of storytelling to communicate science to children can boost and cause stimuli that bring them closer to scientific knowledge and other aspects of scientific and technological culture.

In addition, Lima and Ricardo (2019) consider the interface between science and literature as an extremely relevant tool for teaching, as it allows the reader to have contact with mathematical and scientific concepts described by words belonging to the students' mother tongue, in addition to signs provided by analogies, enabling a "better understanding and transformation of a semiotic system into a more abstract one" (p. 39).

We cannot fail to mention the contributions of Zanetic (2006), one of the Brazilian pioneers of the approximation between science and literature, who defended the potential of approximation between these fields, whether through literary productions that benefit from scientific and technological themes or even scientific productions with literary influences, such as the writings of Galileo Galilei.

Galvão (2006, p. 36) emphasizes that science and literature, "despite having specific languages and methods of their own, (both) win when put into interaction and humanity wins when it realizes the different readings that the two approaches allow it to do". Ferreira and Raboni (2013), when analyzing the book "Twenty Thousand Leagues Under the Sea", by Jules Verne, highlight its potential for scientific dissemination and use in formal teaching situations, as the author intentionally and contextually approaches scientific concepts.

Almeida, Massarani and Moreira (2016, p. 22) also make relevant contributions by highlighting the "convergence of science and cordel for a closer approximation between popular and scientific cultures". Lima, Ramos and Piassi (2020) also show the potential of bringing science and literature together, mainly from perspectives that help to understand the interfaces and that criticize the dichotomization between these fields, since these areas can contribute to a complementary understanding and corroborate with science teaching.

Among the contributions of Lima, Ramos and Piassi (2020), it is important to highlight the necessary overcoming of the false dichotomy established between cognition and imagination, both are capacities of human thinking that are interconnected in an integrated functional system (Martins, 2015). Thus, even though creation and imagination go through different paths in scientific and artistic production, both Science and Art base their activity on creation based on cognitive processes that support the creation of the new. Therefore, imagination, whether for Science or for Art, is the source, means and product of these activities, which can only be developed through cognition.

These indications show the relevance of the approximation between science and literature. We allocate these considerations to think especially when this approximation occurs in SC for children.

Thus, seeking to study the SC produced through literary texts for children, this work aimed to analyze the scientific ideas and concepts present in the work of science communication aimed at children "Isaac no Mundo das Particles", written by Elika Takimoto. For that, we take as a reference the contributions of the historical-cultural perspective. We assume that understanding SC characteristics is essential to understand how to improve it and use it in educational situations.

## THEORETICAL REFERENCE

To analyze the presentation of scientific ideas in a children's SC book, we draw on contributions from the historical-cultural perspective. We understand that the theoretical framework was not proposed for literary analysis, however, the discussion about the formation and development of Spontaneous and Scientific Concepts contributes to a deep analysis of the characteristics of knowledge present in SC books.

It is important to emphasize that "consciousness is the reflection of reality refracted through the prism of socially elaborated meanings and linguistic concepts" (Leontiev, 2004, p. 88), that is, through shared experiences, relationships and knowledge, from outside inward, the subject builds his/her consciousness. This means that the book, as a material reality, can constitute a basis for conscious reflection.

Considering that individual consciousness can only exist from the moment that social life exists, the significations can be understood as the bridge between the internal and the external to the subject. Meanings are social productions that have the role of mediating the relationships between subjects and the world, they are capable of being internalized by consciousness and are capable of guiding human behavior. Asbahr (2014, p. 268) emphasizes that significations "are a reflection of the reality historically elaborated by humanity in the form of concepts, knowledge or modes of action, regardless of the individual relationship that men establish with it".

At the current level of development of society, the process of signification is shown to be independent of the individual relationship that subjects establish with the singular reflexes of reality. The current system of significations exists even prior to the subject's birth, and it is up to the subject to get appropriated and transform these significations.

Vygotsky (2018) clarifies that both the higher psychological functions and the significations that make up human consciousness are social products. They are constituted first on the interpersonal level and then on the intrapersonal level. This consideration is fundamental and enables us to use the tools of the cultural-historical perspective to understand processes that are not contained in human consciousness.

Based on historical and dialectical materialism, Vygotsky considers that knowledge is a reflection of objective reality, but to interpret this process as a simple passage from the external to the internal is a mistake. Cheptulin (1982, p. 57) clarifies that: "knowledge begins precisely with practice, which works and develops based on practice and is realized through practice". It is precisely on the basis of practice that the categories in which the connections and universal forms of being are reflected and fixed are formed. The knowledge production process refers to a structural transformation that occurs in the human being's relationship with the world and which may imply a qualitative leap in the human psyche in relation to the psychology of the animal (Asbahr, 2011). Thus, the human being produces a subjective image of the objective world, which is essentially determined by work (Martins, 2015).

Cheptulin also shows that:

> Developing on the basis of practice, knowledge represents a historical process, in the course of which man penetrates more and more deeply into the world of phenomena. In this process, the categories appear in a determined order, each one of them in a rigorously determined stage of the knowledge development. Fixing the universal aspects and connections made evident by knowledge at a given stage of development, the categories reflect the particularities of that stage and are, in a way, degrees and points of support for the elevation of man above nature, for knowledge of the latter (CHEPTULIN, 1982, p. 57).

From these considerations, we can understand that Vygotsky's propositions about *Potential Concepts*, *Spontaneous Concepts* and *Scientific Concepts* are categories that are not restricted to the study of consciousness, since they express objective characteristics of the phenomenon. Thus, we understand the use of this theoretical contribution in the context of this research as relevant.

Next, we present considerations about the main concepts of the historical-cultural perspective that were used in the data analysis. In this sense, it is worth highlighting in particular the relationship between thought and word, since concepts are expressions that articulate both in an indissoluble way. For Vygotsky (2018), the word (concept) intrinsically articulates thought and language, a fact that implies recognizing that every word is a generalization.

Vygotsky (2018) emphasizes that meanings and senses develop historically in the human psyche. When a child learns a word, at its beginning, it is a generalization that refers to basic notions. As the child develops, this generalization is developed in higher and higher degrees, until it reaches the apex of the process in the formation of scientific concepts.

To understand the process of signification, generalization and transformation of the meanings of words, Vygotsky (2018) recognized the following categories: *Syncretic Thinking, Complex Thinking, Potential Concepts, Spontaneous Concepts* and *Scientific Concepts*. For this work, we focus on concepts, as they express more stable and more precise formulations than syncretic thinking and thinking in complexes.

The most elementary forms of intellectual production (syncretic thinking and thinking in complexes) are hardly basic structures in written formulations, as writing requires a high degree of abstraction and hierarchical structuring of ideas. Therefore, for the study of the presentation of concepts in a popular science book, we believe that the consideration of conceptual formulations is more relevant and fruitful.

In addition, it is worth noting that syncretic thinking is understood as a formulation of meanings without a concrete basis, predominantly based on the production of an undifferentiated image, generated from the (subjective) child perception (Vigotski, 2018). In turn, thinking in complexes synthesizes a formulation of meanings based on concrete aspects, related from apparent and non-essential elements - the structure of thinking in complexes is not based on the establishment of abstract and logical relationships, but, above all, on in concrete, factual and fortuitous bonds created by the child (Vigotski, 2018). This condition indicates the lack of stability of meanings and subjective images created through syncretic thinking and complexes.

Based on these considerations, we believe that studies of the presentation of concepts in the book are more pertinent, because, although there may be formulations similar to syncretic thinking and thinking in complexes, the analyses would hardly be productive, since these formulations of meanings are unstable.

Vygotsky (2018, p. 246) understands that concepts are more than a sum of certain associative links formed by memory, that is, they are more than a mental habit. They are "a real and complex act of thought that cannot be learned through mere memorization, but can only be performed when the child's own mental development has already reached its highest level".

According to Vygotsky, the *Potential Concepts* are constituted by concrete and functional meanings, which are found at the origin of abstraction.

> [...] they play a very important role in the evolution of children's concepts. This role consists in that, for the first time, by abstracting certain attributes, the child destroys the concrete situation, the concrete link of the attributes, and thus creates the indispensable premise for a new combination of these attributes on a new basis. Only the mastering of the process of abstraction, accompanied by the development of thinking through complexes, can lead the child to form concepts of truth (Vygotsky, 2018, p. 226).

It is possible to observe that the attribute used to group the objects in the Potential Concept presents a prominence in comparison with others. This single attribute, considered privileged, serves as a basis for the inclusion of this object in a grouping based on the similar impressions that the child has of the object, thus helping in the "construction of the generalization of several objects named or represented by the same word" (Vygotsky, 2018, p.225).

*Spontaneous Concepts*, in turn, are formed from the child's personal and everyday experiences. These concepts are based on perception and functionality (Vygotsky, 2018). Almeida, Lima and Pereira (2019) clarify that spontaneous concepts express an unsystematic reflection[1] of the subject, they are based on lived experiences and are disorganized internalized at the beginning of their formulation.

In this sense, the *Spontaneous Concept* cannot yet be considered a conscious concept, because "the attention contained in it is always oriented to the object represented in it and not to the very act of thinking that encompasses it" (Vygotsky, 2018, p. 290). For this awareness to occur, the existence of a conceptual system based on reciprocal relationships of generality that provide the arbitrary use of concepts is necessary.

In turn, the formation of the Scientific Concept begins in the structured activities of the teaching process. Its formation takes place from analytical procedures, not through the relationship with the intuitive sphere and with the immediate perception of phenomena. Vygotsky (2018) clarifies that scientific concepts have mediated relationships with some other concept since their inception. However, "the apprehension of a system of scientific knowledge presupposes a conceptual fabric already widely elaborated and developed through the spontaneous activity of children's thinking" (Vygotsky, 2018, p. 269).

Almeida, Lima and Pereira (2019) clarify that the scientific concept is formulated through hierarchical relationships that are based on logical-abstract relationships. Dias (2014, p. 497) emphasizes that "in scientific concepts, there is a more consistent and systematic organization, with these concepts being mediated by other concepts", so that these relationships require the articulation of several higher psychological functions.

In summary, Vygotsky (2018) clarifies that the scientific concept is determined by a vast system of interactions of some concepts with others. Considering that the scientific concept is a human expression based on logical-abstract relationships and that it contributes to the production of the subjective image of objective reality, scientific concepts are mediating instruments between the human being and the world, therefore, they are capable of guiding human behavior.

In explaining the different conceptual formulations, Vygotsky (2018) shows that these formulations are dynamic and capable of influencing each other. When considering that a concept can only be formulated

from an existing conceptual fabric, Vygotsky points out that *Spontaneous Concepts* are the basis for the development of *Scientific Concepts*, especially at the beginning of their formulation and development stage: "the development of the *Spontaneous Concept* of the child must reach a certain level so that the child can learn the *Scientific Concept* and become aware of it" (Vygotsky, 2018, p. 349).

One of the fundamental differences in the development of *Spontaneous* and *Scientific Concepts* is that, while the former develop from experience, from perception, *Scientific Concepts* develop from abstraction in the sense of apprehending concrete reality.

Although Vygotsky made relevant contributions to understanding the development of concepts, we are not clear on the validity of incorporating these considerations into the analysis of the book. This position is justified as we consider that a literary work can have several characteristics, such as monologic or polyphonic structuring. Considering this, it seems to us that deeper studies are essential for the broader use of cultural-historical psychology considerations. For the time being, the pertinence and validity of the categories on the forms of thought (syncretic, complex and conceptual) is clear.

Since the categories to be used in the analyses were explained, we deal next with methodological issues, a brief presentation of the book and, soon after, the development of the analyses.

## METHODOLOGY

To analyze the presentation of concepts in a children's Scientific Communication book, we selected the work "Isaac no Mundo das Particles", written by Elika Takimoto. We selected this book because it addresses a topic that was little studied in childhood and because of the scarcity of SC books dealing with particle physics. This invisible world is not a recurring and familiar theme in children's daily lives, so the ideas they form about particles can be very diverse.

The analytical procedures had two readings for the recognition of the work, carried out by the first author of the text. Then, two more detailed readings were carried out for the selection and highlighting of keywords and key ideas (when the terminology of the concept is not used, but the meaning is expressed in the narrative) that corresponded to the field of Physics. For the selection of keywords and key ideas, we developed two criteria. The first is terminology, that is, whether the word used in the book is equivalent to a term that represents a scientific concept in the field of Physics. The second criterion was the analysis of the content, seeking to observe whether the utterance has meanings that refer to some scientific concept. To exemplify, we present two excerpts that contain the keyword and the key idea. The first presents several keywords that equate to scientific concepts:

> - From what I've heard in here, **atoms** do exist, in droves. But they are made up of building blocks, or rather, they have a **structure**. They are formed from a tiny dense **nucleus**, where we have what we call **protons** and **neutrons**. But, in addition, they also have something we can consider like a **cloud**, which surrounds them, and which is formed from what they call **electrons.** (TAKIMOTO, 2017, p. 44, emphasis added)

In the excerpt above, we highlight the words atoms, structure (atomic), nucleus (atomic), protons, neutrons, cloud (electronic) and electrons, which refer to scientific concepts, although there are small deletions, after all it would be "atomic structure", "atomic nucleus" and "electronic cloud" (or electrosphere).

The second excerpt presents a key idea regarding collision types:

> [...]
>
> - Well, now we're in a safe place - observed Boson in a corner full of people like him. - What did you want to know again? Oh yes! Got it! You wanted to know why they put my particle friends to bump into each other. For you to understand, answer me: what happens when two objects collide with each other?

- That's an easy one - Argo began. - **They can bounce back and forth, like marbles, or warp and stick together, like two plasticine balls**.

- **Or crash, if it's two glass cups, right**? - completed Isaac. (Takimoto, 2017, p. 40, emphasis added).

The highlighted fragment expresses ideas related to the concepts of collision according to classical mechanics, which can be classified as elastic, inelastic or perfectly inelastic collisions. Evidently, the conceptual terminology is not used by Boson or Isaac, however, the content expressed by the statement in bold refers to the types of mechanical collisions. There is even the signification of a perfectly inelastic collision that is understood when, after the collision, the two colliding bodies carry out the movement with the same speed (when they 'stick together').

Next, we selected the fragments/utterances that established the beginning (partial) and the ending (partial), in which the words or the key idea were, and we analyzed the utterances seeking to identify and understand the characteristics and conceptual relationships between the key words and the scientific ideas present in the text.

The analysis of these fragments was based on the unit analysis method proposed by Vygotsky (2018). Romanelli (2013, p. 206) clarifies that this method "would allow investigating the common denominator between directly interrelated systemic functions. In the case of thought and language, the author identified the meaning of the word as the basic unit, the factor common to these two instances". For this investigation, we use the word as a unit of analysis, understanding that, for the study of the presentation of concepts, meaning and terminology have an essential and indissoluble relationship. Therefore, it was necessary to go beyond the meaning of the word to contemplate the totality of the concept, which is composed of the meaning and the image (sound or visual conjunction).

It is worth mentioning that the analysis was based on the meanings of the words present in the text in order to understand their characteristics and possible codetermination relationships between them. Thus, the conceptual meaning consolidated by scientific knowledge was not the determining element for analysis, but the relationships of signification established in the selected fragments.

Such a methodological choice should not be interpreted in the sense of underestimating the significations consolidated by scientific knowledge. On the contrary, after all, the reason for the development of this investigation is allocated precisely in the attempt to relate the social significations stabilized by the scientific sphere and those present in SC. Thus, understanding the relationships of meaning existing in SC is a fundamental condition for the advancement of an investigation that problematizes (1) conceptual formulations and (2) the correspondence relations with the scientific knowledge present in SC.

It is important to emphasize that the method of analysis by units is also historical, so it is essential that the development and transformation of words are taken into account. We also adopted the premises of Vygotsky (2018), which denote the importance of analyzing the process, seeking to explain it, instead of focusing on the product and description.

We also emphasize that the analyzes were validated by pairs as all authors analyzed the fragments individually, contrasted the results and, in case of disagreement, dialogued in search of the consensus that was reached in all cases. Consensus was reached when one of the researchers convinced the others of a certain interpretation. Fragment 3, present in the analysis section, was the only one in which there was greater divergence between the researchers' initial interpretations; the others were adjustments. Next, we make a brief description of the book to contextualize the work.

## ISAAC IN THE WORLD OF PARTICLES

The book "Isaac no Mundo das Particulas" was written by Elika Takimoto, professor at CEFET/RJ, after participating in the CERN School of Physics program - a course offered by the European Organization for Nuclear Research (CERN) in partnership with the Brazilian Society of Physics (Sociedade Brasileira de

Física - SBF) and with the support of CAPES - Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Higher Education Personnel Improvement Coordination, in Brasil).

In order to approach the theme for children, the work tells the story of Isaac, a curious child who, after playing on the beach, begins to reflect on the small particles of sand. Isaac takes home a single grain of this sand, which later reveals to be Argo, a character with anthropomorphic characteristics, that is, characteristics associated with human forms, including the ability to communicate using language, as we can see in the excerpt next:

> - You... you... you speak? – asked Isaac, very surprised.
>
> - Of course I speak! May I know where I am? Why did you bring me here? Where are my brothers? – asked the half-enraged grain.
>
> - Your brothers? How come does a grain of sand have brothers? Are you going to tell me you have a name too?! replied Isaac, asking more questions. (TAKIMOTO, 2017, p. 14)

Argo's and Isaac's imagination allows them to visit different places and historical moments that contribute to answer the question "What are things made of?", central to the narrative. Using a cardboard box in the shape of a space rocket, Isaac and Argo set off, using their imagination, to Ancient Greece (400 BC.), in order to converse with Democritus, Leucippus and later with Aristotle. In addition to Ancient Greece, on one of his imaginary journeys led by Argo, Isaac is guided on a visit to CERN, where he meets the Higgs Boson [an equally anthropomorphic character]. It is at CERN, during the conversations with Boson [character], that the central question of the narrative is answered according to the most advanced scientific knowledge.

## SYNTHETIC PRESENTATION OF DATA

The execution of the analytical procedures led us to identify and analyze 37 key words or ideas that will be presented below in Table 1. For further analysis, we selected three of them, referring to the concepts of (1) Particles, (2) Vacuum and (3) Atoms, which were analyzed. The choice of these concepts took as a criterion the frequency of these words or ideas in the book, associated with the volume of explanations made about each of them, as well as their relevance in the work.

To organize the analysis, we present Table 1 below, which summarizes the key words and ideas present in the book. In the first column are the detailed terms, while the second column indicates the pages where they can be consulted.

Numbers written without highlighting are appearances of concepts in history, but unaccompanied by an explanation. This is due to the concept not being the focus of the current discussion or being used as a support for other concepts. Pages highlighted in bold indicate mentions of key words and ideas that are accompanied by a discussion and/or explanatory deepening.

In addition, the concepts that are presented in the book are indicated with an asterisk, however the character does not synthesize or use the conventional terminology used by scientific knowledge. For example, Boson [character] explains surface density, without using the term "surface density".

**Figure 1.** Table of Key Words and Ideas in the book Isaac no Mundo das Partículas[2]

| Key Words and Ideas | Pages | Key Words and Ideas | Pages |
|---|---|---|---|
| Acceleration | 37, 51 | Movement | 19 |
| Antiparticles | **53** | Neutrons | **44**, 57 |
| Atoms | **19**, 20, **24**, **25**, 31, 44, 57 | Atomic nucleus | **44** |
| Higgs' boson | **60**, **62** | Particles | 10, **19**, 31, 39, **42**, **43**, 44, 51, 53, 60, 61 |
| Higgs' field | **61**, **62** | Elementary particles | **42**, **44**, **51** |
| Electrical charge | **53** | Exchange particles | 44 |
| Collisions | **40**, 45 | Weight | 7 |
| Cosmos | 28 | Pressure | 35 |
| Surface density | **47/48** | Position | 19 |
| Distance | 37 | Pair production | **49**, 54, 57 |
| Electrons | 43, **44**, 57, 61 | Optical properties | **51** |
| Energy | 41, 43, 52, 54, 61 | Protons | 43, **44**, 57, |
| Atomic structure | **44**, 49 | Quarks | 39, **44**, 57, 61 |
| Frequency | 33 | Sound | 33 |
| Faraday's law | **44** | Temperature | 35 |
| Leptons | 44 | Vacuum | **25**, **52**, **53**, 54, 56 |
| Atomic bonds | **32** | Velocity | 40, 42, 43, 52 |
| Matter | 41, 60 | Volume | 47 |
| Mass | 60, 61, 62 | | |

## DISCUSSIONS AND ANALYSIS

The insertion of all characters in the story happens through Argo's imagination. This can be noticed when the conversation with Aristotle, appearing to be a young adult man, takes place a few meters from where Leucippus and Democritus, also young adults, were talking. It is noteworthy that Democritus, Leucippus and Aristotle did not live at the same time. Aristotle (384 BCE - 322 BCE) was born about fourteen years before the death of Leucippus (n.d. BCE - 370 BCE) and Democritus (460 BCE - 370 BCE), which corroborates the argument that the author did not aim to address rigorously the history of atomistics, but to use resources to establish a feasible narrative to develop a work of Dissemination of Science for children.

The imaginative character present in the work is treated as a fundamental subjective factor both for the accomplishment of the work and for the scientific doing. For Silva (2006, p. 5), "the scientist is led to imagine, to presuppose, no matter how rigorous their schemes are, that the schemes themselves act in the unknown, and, sometimes, the scientific text can incorporate this inaccuracy".

In this first interaction, the concept of vacuum begins to be worked on. In addition to it, 36 other physical concepts are worked on, based on key words or ideas. Elementary concepts, such as atoms and particles, are used frequently at the beginning of the book, but, as the narrative progresses, the complexity gradually increases and more elaborate concepts, such as the Higgs Field and the Theory of Relativity, are introduced.

Unlike the table and for better visualization of the development of concepts in the narrative, the analyzed fragments are arranged in chronological order. Takimoto's work mobilizes concepts, stories, procedures and subjects that, in one way or another, contributed to the development of the field of Particle Physics, and, right at the beginning, the first words and key ideas used introduce the concept of Particles.

It all starts with Isaac's question: "Is there anything in the universe smaller than this tiny grain [of sand]?" (Takimoto, 2017, p. 10). The fragment is shown below, and to facilitate the visualization of the key words and ideas, they have been highlighted in bold.

**Fragment 1**

1. He got up carefully, pressing that **small**, almost spherical **body** between his fingers. He was less frightened by the immensity of the world than by the possibility of losing that **such small part** of the cosmos forever. "If I drop this **particle** of sand, I'll never be able to catch it again. It's true that Isaac could pick up countless other grains that were under or near his feet, but not exactly the one he'd tickled with a gusty breeze, gust, or perhaps hurricane.
2. [...] At first, he even thought that the **small particle** had run away, but soon he found a **very tiny ball** in the corner of the cute container. Just look at that little grain and he was already starting to think about some nosy things.
3. - Is there something in the entire Universe littler than this **teeny grain**? (Takimoto, 2017, p. 10, emphasis added)

The keyword "particle" appears in paragraph 1. This keyword is linked to the characteristic related to the size of the grain of sand in relation to elements that surround it and with Isaac himself. To reinforce the characteristic related to grain size, this meaning was expressed six times in this three-paragraph excerpt (**small body, such small part**, **particle, small particle**, **very tiny ball**, **teeny grain**), among uses of the word or synonyms. The indiscriminate use of this meaning seems to be a strategy of introducing and anticipating the concept linked to the keyword, which in this case produced a *Potential Concept* due to (1) its connection to the concrete and (2) its functional use.

It is interesting to note that the *Potential Concept* is surrounded by *Spontaneous Concepts* produced by Isaac's experiences and sensations, so the word *particle* has a functional use and its meaning is based on the idea of small size from spontaneous meanings present in children's daily lives. Therefore, with each use, the *Potential Concept* is increasingly generalized and the formation of the *Scientific Concept* becomes closer, as any expansion in the generalization process mobilizes new relations of meaning. If, on the one hand, these new meanings are capable of establishing logical-abstract relationships, on the other hand, they induce the ascent from the abstract to the concrete through the mobilization of spontaneous concepts.

Starting from the reflections of the previous fragment and conversations with Argo, Isaac is guided imaginatively by Argo to ancient Greece, where Democritus and Leucippus talk about the atom, what they believe to be the smallest constituent particle of matter:

Starting from the reflections of the previous fragment and conversations with Argo, Isaac is guided imaginatively by Argo to the Ancient Greece, where Democritus and Leucippus talk about the atom, which they believe to be the smallest constituent particle of matter:

**Fragment 2**

4. Democritus - Nature, Leucippus, is composed of an unlimited number of indivisible **particles**: **the atoms**. The Universe is composed of an infinity of **atoms** that collide and recoil in an eternal **motion**, through space.

5. Leucippus - Yes, Democritus, certainly yes. And the great variety of materials in nature must come, therefore, from the **movements** of these **atoms**, which, when **colliding**, **form larger sets**, generating different bodies with their own characteristics.
6. Democritus - Surely, Leucippus. And so color, smell, taste and everything else is certainly a result of the **positions** and **movements** of the **atoms**, which cannot be seen or touched.
7. Under the table Isaac couldn't help himself:
8. Isaac – Argo, if **atoms** cannot be seen, how can Democritus say that they exist? If **atoms** can't even be touched, and everything is made of them, how do we see the world? (TAKIMOTO, 2017, p. 19-20, emphasis added)

In paragraph 4, the author uses the atomistic theory, which considers the atom as the smallest part and constituent of the whole, defended by Democritus and Leucippus. On the one hand, this interpretation has a historical importance for Science, as it portrays the origin of studies on the elements that made up the universe. On the other hand, the incorporation of aspects of the history of science expresses a strategy for the composition of SC's book. This articulation with the history of science is relevant, as pointed out by Ferreira (2013), since it enables the understanding and recognition of scientific knowledge as a historically and socially constructed activity.

The analysis suggests that there is an effort on the part of the author to create a conceptual system from scientific ideas that will support a deepening of the concept of *Particles* and, consequently, a scientific character to the dialogue. The structuring of a conceptual system and production of meanings to scientific concepts through literature was also observed by Lima and Ricardo (2019), who emphasized that the management of everyday language was an aspect that contributed to the elaboration of scientific concepts, a characteristic also featured in Takimoto's work.

The characteristics present in fragment 2 allow us to understand the concept of atoms as a *Scientific Concept*. This category, formulated by Vygotsky (2018), refers to the way knowledge is presented and the conceptual relationships in which it is inserted. Therefore, when we indicate that the term atom is presented as a scientific concept, this occurs because it is formulated by reciprocal relations of determination with other concepts.

In this case, the concept of an atom is determined by concepts such as (1) particle, (2) the relationship, position and motion of atoms constitute all things in the universe including their characteristics, (3) Vacuum, absent at this time, but which is inserted by Aristotle (next fragment) when proposing a denial of the propositions of Democritus and Leucippus. The relationships presented are not vast, but are based on logical-abstract relationships.

Soon after Isaac and Argo follow this dialogue, they are called to talk by Aristotle. At that moment, they begin to debate what atoms are or could be, their shape and how they behave in space. The key idea of a vacuum also begins to be worked on in the narrative from that moment on.

**Fragment 3**

9. Isaac – Sir Aristotle... well, my name is Argo and this is Isaac, my friend. We've come a long way to meet you here. Sir, Isaac wants to know if you agree with the idea of Leucippus and Democritus that all things in the world are made of **very tiny particles** called **atoms**.
10. That's when he said, turning to Isaac:
11. - I don't agree with them. If what they're saying is true, what would those **atoms** look like?
12. -Would they be round like Argo? - asked Aristotle, tickling the grain, which was already chuckling.
13. - I think so, right? Or something like that, - replied Isaac thoughtfully.
14. - And what would there be between them [atoms]? I say this because, even when Argo is with his brothers and sisters, there is a very small space between them, isn't there? What's in that space?

15. - Hey, there's air, right? – risked Argo – If not, we die without breathing.
16. - Precisely, Argo. But what about between atoms? If even the air, as they [Democritus and Leucippus] say, is made of **atoms**, and between **atoms**? Would there be nothing? - asked the bearded man.
17. - Yeah. Nothing, I guess. - Isaac said, while reflecting.
18. - Nothing, really nothing? - insisted Aristotle.
19. - No way! - shouted Argus. – And how do **atoms** breathe? They need air too, don't you, Sir Aristotle?
20. - No doubt, Argo. Furthermore, **what is nothingness**? What would it be made of? If we cannot think of nothing, how can we affirm its existence?
21. Isaac was stunned. Damn, that was hard. He had never stopped to think about nothing. Since when is nothing made of something? But if nothing is not made of nothing, how does it exist? Like that? Out of the blue? (Takimoto, 2017, p. 25, emphasis added)

In the narrative, Aristotle starts from a perspective that excludes the possibility of the existence of atoms, supported by his sensorial and philosophical experience, and reinforces a position that there are no smaller structures or even the vacuum said by Democritus and Leucippus.

Aristotle takes as an example the situation in which Argo is very close to his brothers and similar, so that the situation on an atomic scale is understandable. Argo relies on the comparison made by Aristotle and mechanically reproduces the signs and meanings appropriated by him in his personal experience (paragraph 15), as occurs when there is a formulation of a *Spontaneous Concept*.

When comparing fragments 2 and 3, it is possible to perceive that the narrative carries out a deconstruction of the scientific concept towards the spontaneous concept, a fact that implies the inversion of the order of development of rational abstraction. The denial of the conceptual proposal of the Atom is based on the relationships between elements of a structure, which in this case can be summarized by the Matter--Non-Matter dichotomy (vacuum). In this situation, the negation of the atom is based on the sensorial and anthropomorphic interpretation (atoms breathe), a fact that indicates the formulation of a spontaneous concept. Only at the end of the fragment there is an abstract development denying the existence of nothingness, but it seems to us that this meaning happens to strengthen the 'spontaneous' elaboration.

Still in the same fragment, the idea of a vacuum is presented for the first time. When Isaac explains that he had never specifically thought about "nothing", he is using a key idea about the vacuum that refers to a *Scientific Concept*, which is present in the proposition of Democritus and Leucippus, which states that the vacuum is synonymous with the absence of matter, and that, despite being used in the narrative, this line of thought is not presented in the dialogues that took place between paragraphs 9 and 21, but can be noticed by Aristotle's induction.

This way, we understand that the concept linked to the word Vacuum, in the previous excerpt, is wrong from a scientific point of view, since there is no correspondence with its meaning, but it was classified as a *Scientific Concept* because it is inserted in a widely elaborated conceptual fabric, formed by the concept of particles (1), atoms (2), space (3), collisions (4), motion (5), positions (6), larger sets (7), etc. The scientific concept of Vacuum, in this case, is not included in the negation system proposed by Aristotle, this indicates that it is part of the logical-abstract relations of determination of the concept of Atom by Democritus and Leucippus, present in fragment 2.

In the previous fragment, words, concepts and key ideas that should support the development of the scientific concept of Atoms, such as (1) Particles, (2) Space and (3) Vacuum, are invalidated by false arguments that mainly use sensory experience of Aristotle and Argo.

In the fourth fragment, presented below, the keywords Particles and Atoms are used again:

**Fragment 4**

22. - Argo! I've been thinking... if people used to have so many cool ideas without having equipment, what about today? How is this done? Do you already know if the **atom** exists?
23. - Not only do you know that the **atom** exists as well as they know that there are millions of **particles** inside it.
24. - Millions? But wasn't it supposed to be the smallest **particle** in the universe? If there are things inside it, then now they are the **atoms** and the **atom** has become something else, right? Something bigger than the smallest **particle**.
25. - Yeah... It could be... Now we have a bunch of "**atoms**" forming a "**big fat atom**". But the "**big fat atom**" remains an **atom**, because it remains, let's say, the brick that forms all houses, even if the brick can be broken in half (Takimoto, 2017, p.31, emphasis added).

Starting from the ideas of Democritus and Leucippus, Isaac asks, in paragraph 24, that the atom should no longer be called that way, since it is no longer considered the smallest existing particle. This position was, possibly, selected by the author because, etymologically, the word atom derives from the Greek *atomos*, which means *indivisible*.

This denial on the part of Isaac demonstrates a contradiction that refers to the difference between the literal meaning of the word atom and its concept. In this sense, the literal meaning appears as an obstacle to the formalization of the *Scientific Concept*, which is constituted by a conceptual network and not by a specific definition.

In the previous fragment, Argo uses an analogy to deconstruct the idea that the atom is the smallest constituent particle of matter, but particles smaller than atoms are not named. The naming and categorization of these smallest units occurs on page 39 with the name quark, and on page 41, when the keywords related to protons and electrons appear, and the process of generalization and formation of a conceptual network continues. That said, we understand that the way both keywords are used refer to concepts developed in the field of practical knowledge, showing the beginning of a transition process from the concrete to the abstract, as can be seen in the *Potential Concepts*.

In the following fragment, the development of the keyword and the concept of particles continues and the keyword *quark* is mentioned for the first time. Unlike previous presentations, in this excerpt the author inserts keywords now unknown to Isaac and Argo, when approaching, in an introductory way, the experiment carried out inside CERN.

**Fragment 5**

26. - Shhhh. Lower your voice. They're looking for me everywhere. My name is **Higgs Boson**. What do you want to know anyway?
27. - Basically, Mr. **Boson** (or Mrs. **Boson**?), everything that concerns this place. - replied Isaac softly.
28. - Good. You are talking to the right **particle**. I have no gender. You can refer to me as you wish. But first let's go somewhere no one can find me. If they find me, they will do to me what they're doing to my **particle** friends. Spinning them around until they're really dizzy and then POW! They make one **collide** with the other until they become crumbs of **quarks**,- explained Boson, biting its nails and looking around terrified.
29. - Crumbs of what? Why do they make your friends bump into each other? - asked Argo, who felt like a giant as he walked very quickly behind that tiny **particle**. **Boson** did not even answer, so worried was heabout hiding (Takimoto, 2017, p. 39, emphasis added).

In paragraph 26, the first appearance of the character Boson occurs, which makes a clear allusion to the Higgs Boson, an elementary bosonic particle that supports the Standard Model of Particle Physics. In that same paragraph, it says that they are looking for it everywhere, which refers to the long period required for the detection of this particle: 52 years.[3]

In paragraph 28, Boson identifies itself as a particle, making the word *particles* also encompass this being "unknown" until then, making it increasingly generalistic. In this paragraph, the keyword *quarks* is introduced, still as a *Potential Concept* that is based on the functional use of the word, referring to a type of particle. Boson [character] cites this type of elementary particle, but the development of the idea takes place later.

The use of the keyword as a potential concept may have happened to instill curiosity in Argo, Isaac and, simultaneously, in the reader of the work. Considering that curiosity is one of the factors that culminate in learning without prejudice to content for children (Scalfi & Corrêa, 2014), it seems to us that the author uses this tool for the composition of the book, a characteristic that can also be found in other passages of the work.

After the dialogue that took place in the previous fragment, Boson [character] finds a safe place for the conversation with Isaac and Argo to continue and then tries to explain to them why they are forcing their friends to collide. In this dialogue, Boson begins the explanation starting from the fact that the matter generated in these collisions can be constituted of energy, which Isaac later names "solidified velocity".

Isaac enters a state of confusion and denial, as the phenomenon cited is counterintuitive. In order to elucidate the solidification of speed, the author, through Boson [character], uses an analogy, as shown in the following excerpt:

**Fragment 6**

30. - How smart, **Boson**, if I can't understand this? By the way, does anyone understand? - asked Isaac, stunned by the rather crazy idea.
31. - Well, actually, it's very difficult to visualize this phenomenon because we can't find anything like it on a daily basis. But we can try to imagine this strange creation of **matter**. It's as if the energy materializes, turning into a kind of extremely fine dust. Like a dust of **energy**, can you visualize? So, this "dust" is what scientists call "**particles**". Look at me! I am a kind of "**particle**"!
32. - Come on, **Boson**! Jeez! Are you going to say that you disappear when you run? (- Isaac said) (Takimoto, 2017, p. 41-42, emphasis added)

In this fourth appearance, the generation of particles was mobilized in paragraph 31 through analogy. When Boson [character] says that energy materializes and becomes "like a dust of energy" and that this "dust" is what scientists call particles, it refers us to the figure of speech that was used by Argo in the second appearance of the same keyword, in paragraph 25, in which Argo says that the atoms form the "big atom", the "dust" being a particle that composes it.

When we think of the atom as a brick, as in paragraph 25, and we start breaking it down more and more, at some point we will only have very small fragments or even dust. Two different characters (Argo and Boson) used a complementary line of thought so that Isaac understood which particles exist inside the atom and, in order to find them, it is necessary to "shatter" the atom.

On the next page, we find another use of the keyword particles. This time the particles are defined and the protons and electrons are mentioned. Here Boson makes an analogy that protons and electrons are the "carts" that are used in collisions. It seems to us that the use of these analogies are attempts to establish a relationship between the *Spontaneous Concept* (with a cart) and the *Scientific Concept*, with the aim of formulating the latter. The excerpt is below.

**Fragment 7**

33. - "As if it were real," Isaac replied with his eyes closed.
34. - Well, friend. But adults can't be satisfied with just the world of ideas... So they made these giant detectors and **accelerators** that find the "carts", which are the **particles** they call **protons** and **electrons**, and make them move at extreme **velocities**.
35. - But why do these **accelerators** and detectors have to be so big, if you are so small? - asked Isaac again.

36. - Because they want the **protons**, for example, to acquire a lot of **energy** to be able to **collide** and **crash**, so that they can detect the **particles** that will emerge from this **collision**. They know that the tighter a curve, or rather, the smaller it is, the more **energy** is lost along the way. If the intention is to **accelerate** these **protons** a lot, to the point of generating a very high **energy** that is not easily lost, the **protons** have to go through large circles. Huuuuuuuge circles. (Takimoto, p. 43, emphasis added).

Right after naming the particles, in paragraph 36, Boson explains the basic structural schematic of the Large Hadron Collider (LHC), its circular arrangement, its operation and the objective of carrying out the collisions of these particles using such equipment. In the sequel, Isaac is curious about why using magnets to accelerate the particle, if they aren't made of iron. Boson discusses the matter, but without mentioning the spin magnetic moment, making it clear that protons and electrons were not magnets, but behaved as one in certain situations. Then Isaac resumes the discussion of the existence of the atom, as shown in fragment 8, below.

**Fragment 8**

37. - No. Or rather, yes... - assimilated Argo. - I understand what you mean. Interesting.

38. **- Boson**, so **atoms** really exist? Isaac resumed his big question. - And are they even the smallest **particles** found in nature?

39. - From what I hear here, **atoms** do exist, in droves. But they are made up of building blocks, or rather, they have a **structure**. They are formed from a tiny dense **nucleus**, where we have what we call **protons** and **neutrons**. But in addition to that, they also have something that we can think of as a **cloud**, which surrounds them, and which is made up of what they call **electrons**.

40. - And these protons, electrons and neutrons are the smallest particles we have in the universe? - Isaac insisted.

41. - Not yet - replied Boson calmly. - Basically, this entire structure of **protons, electrons** and **neutrons** is formed by three types of **elementary particles**, which are called **quarks**, **leptons** and **exchange particles**. I think that's what you're asking about. **Elementary particles** are those that cannot be broken, or rather, divided.

42. - That's what he wants to know! And what are they like? Round like me?! - Argo asked, rubbing his belly (Takimoto, 2017, p. 44, emphasis added)

In paragraph 38, Isaac again asks for confirmation of the existence of atoms, but this time he asks Boson [character], in addition to returning with the positioning of Democritus and Leucippus in the narrative. When Boson answers him, he uses an analogy identical to the one Argo used in the second appearance of the keyword "particles", referring to bricks/building blocks (paragraph 25). In excerpts 39 and 41, Boson provides a detailed explanation of the general atomic structure, including the nucleus and the electrosphere (although it does not use this term), as well as indicating where protons, neutrons and electrons meet and what are the elementary particles. It seems to us that here "the scientific discourse assumes the position of a reinforcing element of the fictional discourse, of the situations announced in the adventure and vice versa", as observed by Ferreira and Raboni when analyzing a work by Jules Verne (2013, p. 94).

In paragraphs 39 to 41, concepts already worked and new words and key ideas are used as support in the process of formation of the *Scientific Concept of Atoms*, such as (1) particles, (2) structure, (3) nucleus, (4) protons, (5) neutrons, (6) cloud [electronic], (7) elementary particles, (8) quarks, (9) leptons and (10) exchange particles. Therefore, by explaining to Isaac and Argo the particles that make up the atom, Boson begins a process of expanding the network of elements that are used to determine what it is.

The particle concept also gains new contours after this fragment. When he began his search for answers, Isaac was curious to know what was the smallest particle that made up matter. This formation process began in the first fragment, in paragraphs 1 to 3, when the keyword "particles" appears in the form of a *Potential Concept*. During the development of the narrative, situations of use of the word were made explicit,

making each fragment become more generalistic, but still linked to its practical use. Therefore, the term Particles was presented at that time as a *Potential Concept*.

The formation process continues when the atomic structure is introduced into the narrative. From that moment on, the characteristics and particularities of electrons, protons, neutrons and other subatomic particles are presented, generating multiple determination relationships and enabling the development of a conceptual support network. Throughout the presentation of subatomic particles, procedures to which these particles are subjected are discussed, such as increasing their speed and colliding them in a hadron collider, so that the characteristic processes of the field of study of particle physics serve as a foundation for the concept development.

Thus, the formation of the *Scientific Concept of Elementary Particles* began to be based on (1) the *Potential Concept of Particles*, (2) relationships with other concepts presented in the narrative, forming an elaborate support network, (3) characteristics of subatomic particles and (4) processes and phenomena characteristic of the field of study of Particle Physics. It is worth mentioning that, in the excerpt, some concepts that determine what particles are, have more characteristics of *Potential Concepts* than *Scientific Concepts*, as is the case of quarks, leptons and exchange particles, which were addressed in later moments of the narrative. However, when we focus on the particle concept, between paragraphs 33 and 42, the author presents the correlation structure between concepts, that is, it is the moment when there is a first formulation of the *Scientific Concept* that will be developed and strengthened throughout history.

Below we present the fragment where the keywords *Particles* and *Vacuum* are explored concomitantly.

**Fragment 9**

43. - "(...), but the worst comes now: An object can never be born from nothing, but **particles** can be born from the **vacuum** [said Boson].

44. - So Democritus and Leucippus were right and Aristotle was wrong? Does a **vacuum** exist in the world? – asked Isaac, remembering other trips he and other human beings had already taken.

45. - You've got to be very careful. The **vacuum** we speak of here is not the same as that of Democritus. Democritus' **vacuum** was synonymous with absolutely nothing. Today, despite the fact that there is **no matter** in the **vacuum**, scientists are not able to eliminate from within it, with the theory that is being worked here at CERN, a minimal amount of **energy**, in addition to something they call the **electromagnetic field** and **gravitational field**. (Takimoto, 2017, p. 52, emphasis added)

Boson and Isaac use the keyword Vacuum, but differences between the meanings attributed to it by different theoretical proposals are made explicit. Boson uses, in paragraph 43, the keyword referring to the scientifically accepted concept of Vacuum, in order to approach the phenomenon of Pair Production, but the keyword Vacuum that appears in paragraph 44, used by Isaac, refers to the *Scientific Concept* of Vacuum defended by Democritus and Leucippus and denied by Aristotle in fragments 2 and 3.

When put in comparison, Isaac and Argo are using a wrong *Scientific Concept*, and, upon realizing it, Boson [character] begins a process of resignifying this term, so that the process of forming a scientifically correct *Scientific Concept* can proceed. In this example, it is evident that one of the author's strategies for the presentation of the most appropriate scientific concepts is based on the transition of a concept presented in the narrative, whether *Potential, Spontaneous or Scientific*, towards the formation of a scientific concept more complex and consistent with scientific advances on the subject.

Exposing the facts that lead the Vacuum to not be considered an empty space, Boson discusses the electromagnetic and gravitational fields. In this snippet, the vacuum keyword appears again, as shown below:

**Fragment 10**

46. - Someone or something is nearby. And even if you don't see it, you're feeling the "**field**" of that something.

47. - "I see," said Isaac. - And we can't eliminate this kind of thing from the **vacuum**?

48. - The physicists here believe not. Therefore, the **vacuum** cannot be considered as completely empty. In addition, in these spaces there is also the presence of **particles** and **antiparticles** that are being formed and destroyed all the time.

49. - **Antiparticles**?! - asked Isaac and Argo at the same time. (Takimoto, 2017, p. 53, emphasis added)

Boson summarizes once again that Vacuum does not mean "absence of everything", thus questioning the idea of absolute vacuum. In this fragment, it is evident the expansion of the logical/abstract relations of the concept of vacuum with other concepts, such as: "field", "particles", "antiparticles", "void", among others. Even though these can still be configured as *Potential Concepts* (antiparticles) or *Spontaneous Concepts* (fields), the structuring of the concept of Vacuum is strengthened in the sense of its constitution as a *Scientific Concept*.

In the following excerpt, Boson, when questioned by Isaac, ends the process of forming a *Scientific Concept* in the narrative, through an explanation.

**Fragment 11**

50. - But if nobody detects them [antiparticles], why are we talking about them? Why should we care about this crazy idea that is just an idea and why can't we just consider Democritus' **vacuum**? asked Isaac.

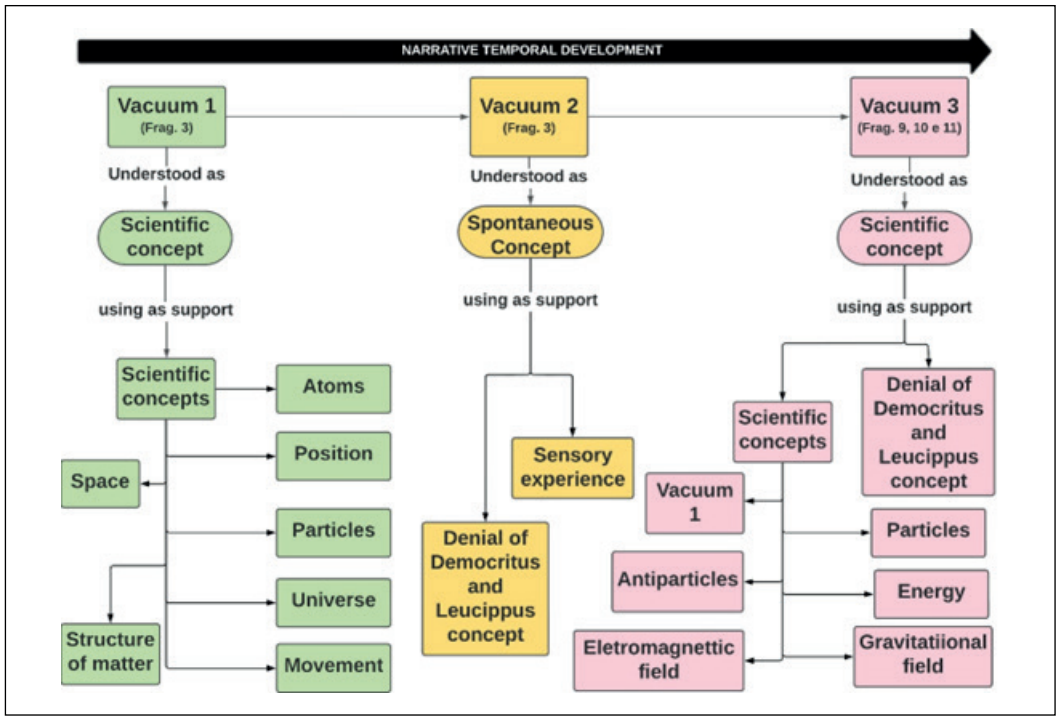
51. - Because we perceive its effects. For example, a blind person cannot see the sun, but perceives its heat. These **particles** and **antiparticles**, which are actually also **particles**, despite not even tickling these huge detectors here, are capable of imparting some **energy** to the vacuum, and the consequence of that is very real. (Takimoto, 2017, p. 56, emphasis added)

The relationships formed between all the concepts presented above are fundamental so that, in this fragment, a solid base is the necessary support for the *Scientific Concept*, scientifically correct, of Vacuum to be expressed. It is interesting to note that the process of presenting the *Scientific Concept* of a vacuum is not direct or has a linear path. The Void was presented throughout the work in a contextualized way amid the dispute of arguments initially established by the interpretations of Aristotle and Democritus and Leucippus. This strategy of inserting physical concepts in highly contextualized situations "allows the reader to construct meanings, indispensable for an effective understanding of the object of study", as indicated by Ferreira and Raboni (2013, p. 93)

The level of development of the presentation of ideas and the narrative makes the main theme of the discussion strengthen both the central concept of the discussion and the concepts involved in codetermination. For example, in the fragment above, the main theme of the discussion refers to the vacuum; however, the discussion contributes to the understanding of the concept of particle, since both have a codetermination relationship. The author developed a plot that articulates the temporality of the presentation of ideas and their correlation, a condition that seems to contribute to the process of elaboration of meaning carried out by the interlocutor for concepts as complex as those approached by Elika Takimoto.

As a synthesis of the analyses, we present below three images, which seek to verbally-visually organize the different forms of presentation of the concepts that we selected for the analysis and their evolution throughout the narrative.

**Diagram 1. The concept of vacuum[4]**




In diagram 1, we present the synthesis of the development of the vacuum concept. We relate the use of key words and ideas linked to the concept in question with other key concepts and ideas that are present in the excerpts. In this way, the diagram makes visible the movement of conceptual formation that begins with the use of the word Vacuum in fragment 3 (Vacuum 1) and ends in fragment 11 (Vacuum 3).

**Diagram 2. The concept of Atoms[5]**

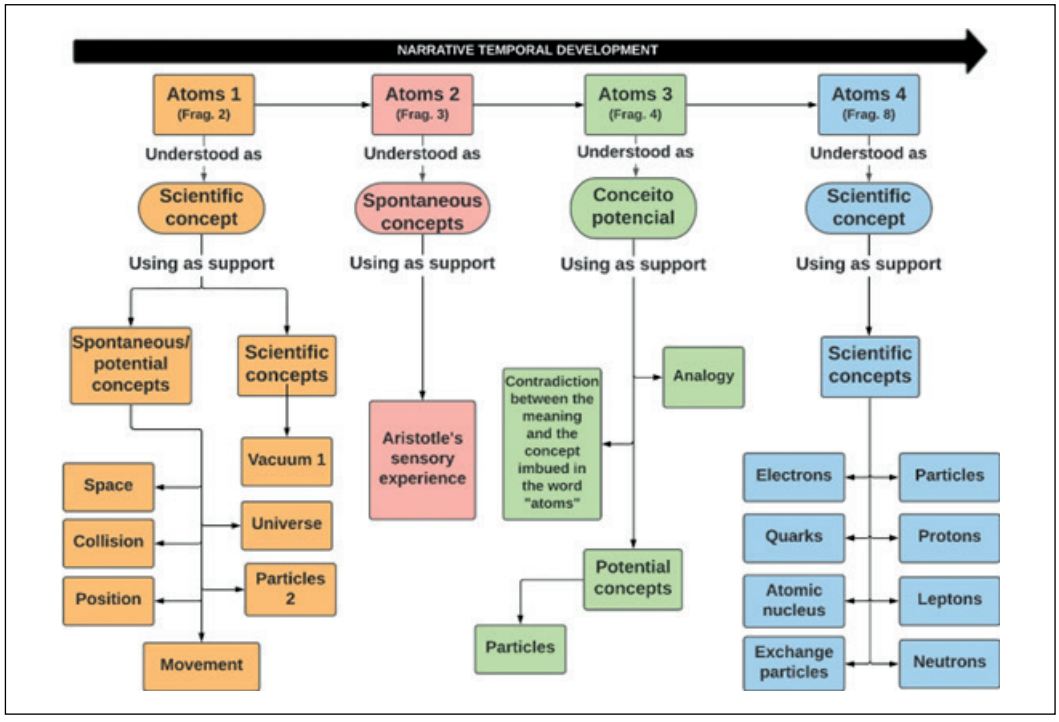
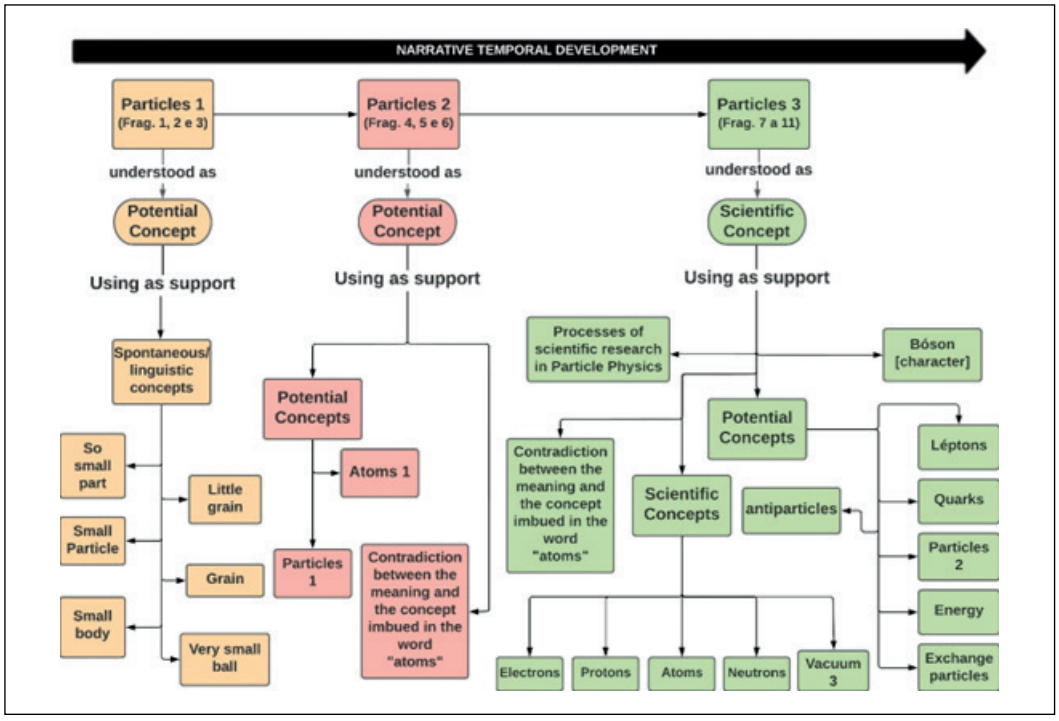


Diagram 2 presents the development of the concept of Atoms in the narrative. In its first appearance, in fragment 2, the keyword Atoms (1) is categorized as a *Scientific Concept*, but, in its next two uses, in fragments 3 and 4, there is an attempt to deconstruct the *Scientific Concept* that culminates in the formation of a *Potential Concept*. In fragment 8, the keyword Atoms (4) is used and inserted in a broad conceptual system. Due to the characteristics of its presentation, it is categorized as a Scientific Concept.

**Diagram 3. The concept of particles[6]**




The third diagram presents the development of the word and the key idea of Particles. In its first uses, the keyword Particles (1) can be understood as a *Potential Concept* due to its link with the concrete and with the functional use of the word. In fragments 4, 5 and 6, the keyword is still understood as a *Potential Concept*, but this time it is used to support other potential concepts. It is in fragments 7 and 11 that the consolidation of a *Scientific Concept* of Particles (3) takes place, when the author presents the existing correlations between the concepts and provides the necessary basis for such.

## FINAL CONSIDERATIONS

In this work we aimed to analyze the scientific ideas and concepts present in the work of scientific dissemination aimed at children "Isaac no Mundo das Particulas", written by Elika Takimoto. For that, we analyzed the book, based on the contributions of historical-cultural psychology, especially in the formulations about the formation of concepts.

It was possible to observe that, throughout the narrative, there were efforts to present scientifically correct concepts, considering the main ideas and keywords analyzed in the work. For this to happen, the author introduced about 37 concepts related to the field of Physics, which proved to be fundamental for the development of the narrative and the Scientific Concepts present in the work.

Although some concepts were merely mentioned, they were used to build a solid base in the process of awareness and logical structuring of more complex concepts present in the book. Thus, we can conclude that

the conceptual approach to scientific ideas developed and became more complex throughout the book. It is evident the development of still precarious elaborations and with little or no relationship of codetermination at the beginning of the book in complex elaborations established in the midst of codetermination relationships.

The volume of scientific ideas and concepts discussed in the book demonstrates the complexity of producing a popular science text for children, since it is necessary to work with the simultaneous development of several concepts. Thinking about the presumed reader and the specificity of scientific language are important criteria for the production and edition of the book, since the presumed addressee determines (or at least should determine) both forms of exposition and the level of depth of the scientific approach.

Considering that the process of concept development in the human psyche begins when the child becomes aware of a word (Vygotsky, 2018), it must be made available from a very early age so that children can begin to establish the first conceptual formulations, even if in a functional way, as well as potential concepts. It is from these formulations that children will be able to produce increasingly refined, logical and abstract generalizations during their developmental process. These considerations corroborate the notes of Lima and Ricardo (2019), when they show that pseudoconcepts, developed by students through reading, developed into scientific concepts after the teacher's performance. Although the results of this research were not based on a school investigation, we understand that the work of SC itself or other instruments or mediating subjects can also contribute to the formulation of scientific concepts by SC consumers, considerations that can be deepened in future investigations.

Therefore, the production of scientific communication supports from potential concepts towards scientific concepts, with the mediation of spontaneous concepts, seems to us to be a promising strategy for the public communication of scientific and technological culture.

For all that has been presented, we understand that the study on the formulation of scientific concepts present in scientific dissemination can contribute both to the field of research and to the production of materials intended for the public communication of science, whether for children or adults. However, in addition to understanding how these concepts are elaborated in scientific dissemination materials, it is necessary to research how readers formulate scientific concepts based on certain conceptual configurations proposed by SC.

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## REFERENCES

Almeida, C., Massarani, L. & Moreira, I. C. (2016). Representações da ciência e da tecnologia na literatura de cordel. *Bakhtiniana:* Revista de Estudos do Discurso [online]. *11*(3), 5-25. https://doi.org/10.1590/2176-457324278.

Almeida, S. A. (2020) Divulgação científica para crianças: uma análise de artigos das revistas Ciência Hoje das Crianças e Recreio. *Revista Ciências & Idéias, 11*, 01-18.

Almeida, S. A., Lima, G. S. & Pereira, B. L. A. (2019). Des/fiando diálogos sobre o conceito de cadeia alimentar em uma aula de Ciências dos anos iniciais do Ensino Fundamental. *Ensaio:* Pesquisa Em Educação Em Ciências (ONLINE)*, 21*, 1-25.

Almeida, M. J. P. M. & RICON, A. E. (1993) Divulgação científica e texto literário: uma perspectiva cultural em aulas de física. *Caderno Brasileiro de Ensino de Física,* Florianópolis*, 10*(1), 7-13.

Asbahr, F. S. F. (2014). Sentido pessoal, significado social e atividade de estudo: uma revisão teórica. *Psicologia Escolar e Educacional, 18*(2), 265-272.

Bueno, C. C. (2012). *Imagem de criança, ciência e cientista na divulgação científica para o público infantil* (dissertação de mestrado) – Instituto de Estudos da Linguagem – Universidade Estadual de Campinas. Campinas, SP, Brasil.

Brasil. Ministério da Educação. Secretaria de Educação Básica (2006). *Orientações curriculares para o ensino médio*. Brasília. 135 p

Cheptulin, A. (1982). *A dialética materialista. Categorias e leis da dialética*. Editora ALFA-OMEGA. São Paulo.

Dias, M. S. L. (2014). A formação dos conceitos em Vigotski: replicando um experimento. *Psicologia Escolar e Educacional, 18*(3), 493-500.

Duarte, N. (2000). A anatomia do homem é a chave da anatomia do macaco: A dialética em Vigotski e em Marx e a questão do saber objetivo na educação escolar. *Educação & Sociedade, 71*, 79–115.

Drigo Filho, E; Babini, M. (2016) A gênese do Inferno e do Purgatório na Divina Comédia de Dante: uma ponte possível entre física e literatura. *Caderno Brasileiro de Ensino de Física, 33*(3), p. 1047,

Ferreira, J. C. D. & Raboni, P. C. A. (2013). A ficção científica de Júlio Verne e o Ensino de física: uma análise de "Vinte Mil léguas submarinas". *Caderno Brasileiro de Ensino de Física, 30*(1), 84-103.

Ferreira, L. M. (2013). *Atomismo*: um resgate histórico para o ensino de química. (dissertação de mestrado) - Programa de Pós-Graduação em Educação Científica e Tecnológica, Universidade Federal de Santa Catarina, Florianópolis.

Galvão, C. (2006). Ciência na literatura e literatura na Ciência. *Interacções, 3*(1), 32-55.

Góes, M. C. R. (2000). A abordagem microgenética na matriz histórico-cultural: uma perspectiva para o estudo da constituição da subjetividade. *Cadernos Cedes, 20*(50), 9-25.

Góes, M. C. R. & CRUZ, M. N. (2006). Sentido, significado e conceito: notas sobre as contribuições de Lev Vigotski. *Pro-Posições, 17*(2), 31- 45.

Grillo, S. V. C. (2006). A divulgação científica na esfera midiática. *Revista Intercâmbio*, (15).

Leontiev, A. N. (2004). *O desenvolvimento do psiquismo*. Lisboa: Livros Horizonte.

Lima, L. G. & Ricardo, E. C. (2019). O Ensino da Mecânica Quântica no nível médio por meio da abstração científica presente na interface Física-Literatura. *Caderno Brasileiro de Ensino de Física, 36*(1), 8-54.

Lima, G. S. &; Giordan, M. (2017) Características do discurso de divulgação científica: implicações da dialogia em uma interação assíncrona. *Investigações em Ensino de Ciências, 22*(2), 83-95.

Lima, G. S., Ramos, J. E. F. & Piassi, L. P. C. (2020). Ciência, poesia, filosofia: Diálogos críticos da teoria à sala de aula. *Educação em revista* (online), v. 36, 1-20.

Lima, G. S. &; Giordan, M. (2021). Da reformulação discursiva a uma práxis da cultura científica: reflexões sobre a divulgação científica. *História, Ciências, Saúde-Manguinhos, 28*, 375-392.

Martins, L. M. (2015). *O desenvolvimento do psiquismo e a educação escolar*: contribuições *à luz da psicologia histórico-cultural e da pedagogia histórico-crítica.* Campinas: Autores Associados.

Massarani, L. (Org.). (2005). *O pequeno cientista amador - a divulgação científica e o público infantil* (1ª ed.). Rio de Janeiro: Vieira & Lent.

Massarani, L. (Org.). (2007). *Ciência & Criança:* A divulgação científica para o público infanto-juvenil (1ª ed.). Rio de Janeiro: Museu da Vida.

Oliveira, M. P. (2015) Divulgação Científica para o público infantil: um instrumento de inclusão social e fortalecimento da cultura científica. In: Encontro Nacional De Pesquisa Em Educação Em Ciências. 2015, Águas de Lindóia. *Anais do X ENPEC*. Águas de Lindóia: ABRAPEC, 2-8.

Reis, J. (1982) Professor José Reis: um divulgador da ciência. *Ciência Hoje*, 1(1), 77-78.

Romanelli, N. (2011). A questão metodológica na produção vigotskiana e a dialética marxista. *Psicologia em Estudo, 16*(2), 199-208.

Ramos, R. (2014). Construção dos objetos de discurso em artigos mediáticos de divulgação científica para crianças. *Redis:* revista de estudos do discurso*, 3*, 156-182.

Rosa, D. & Terrazzan, E. (2002). O uso de Textos de Divulgação Científica para Ensinar Ciências nas Séries Iniciais e a Produção Textual das Crianças. In: *IV Seminário de Pesquisa em Educação da Região Sul*, Florianópolis, SC: Na Contracorrente da Universidade Operacional.

Scalfi, G. A. M. & Micaldas, A. (2014) A arte de contar histórias como estratégia de divulgação da ciência para o público infantil. *Educação, Ciência e Cultura, 19*(1), p. 107-121.

Silva, H. C. (2006). Debate: O que é Divulgação Científica? *Ciências & Ensino, 1*(1), 53–59.

Silva, L. L., Pimentel, N. L. & Terrazzan, E. (2011). As analogias na revista de divulgação científica Ciência hoje das crianças. *Ciência & Educação, Bauru, 17*(1), 163-181.

Silva, S. S. Narrativa literária e ciência. *Ciência & Ensino*, v. l, n. 1, p. 3-8, 2006.

Takimoto, E. (2017). *Isaac no Mundo das Partículas*. Rio de Janeiro: Rocco.

Vieira Júnior, J. J.; Almeida, S. A. (2021). A Teoria Da Evolução Em Quadrinhos: Uma Análise Da Revista Saiba Mais Sobre Charles Darwin. *Investigações Em Ensino De Ciências* (Online), 26, 324-342.

Vigotski, L. S. (2018) *A construção do pensamento e da linguagem*. São Paulo: Martins Fontes.

Zanetic, J. (2016). Física e Arte: uma ponte entre duas culturas. *Pro-Posições*, 17(1), 39–57.

## NOTES

**1** By unsystematic reflection, we understand that the conceptual formulation is not carried out through the establishment of relationships between other concepts, a fact that would form a conceptual system. This expression should not be interpreted in the sense of underestimating the intellectual and creative elaboration present in the formulation of these concepts.

**2** Source: research data prepared by the authors themselves (2022)

**3** In 2012, the A Toroidal LHC AparatuS (ATLAS) and the Compact Muon Solenoid (CMS), two experimental apparatuses at CERN, detected an unknown particle that, in 2013, proved that it behaved, interacted and decayed according to several ways predicted by the standard model, strongly indicating the existence of the Higgs Boson, a particle theorized by Peter Higgs in the 1960s.

**4** Source: research data prepared by the authors themselves (2022)

**5** Source: research data prepared by the authors (2022)

**6** Source: research data prepared by the authors (2022)

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