THE METAPHOR OF COMMUNICATION IN GENETIC INFORMATION CONCEPTUAL COMPREHENSION: AN INVESTIGATION IN INITIAL SCIENCE AND BIOLOGY TEACHER EDUCATION

A METÁFORA DA COMUNICAÇÃO NA COMPREENSÃO DO CONCEITO DE INFORMAÇÃO GENÉTICA: UMA INVESTIGAÇÃO DA FORMAÇÃO INICIAL DE PROFESSORES DE CIÊNCIAS E BIOLOGIA

LA METÁFORA DE COMUNICACIÓN EN LA COMPRENSIÓN DEL CONCEPTO DE INFORMACIÓN GENÉTICA: UNA INVESTIGACIÓN DE FORMACIÓN INICIAL DE PROFESORES DE CIENCIAS Y BIOLOGÍA

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ABSTRACT: In the present context of technological sophistication, Science Education might train citizens to be able to participate in individual and collective decision making. The concept of *genetic information* is relevant for the comprehension of socioenvironmental problems, such as genetic modified organisms and genic therapy, for example. Considering the possibility of this concept to provoke misconceptions by metaphor in learning, we aimed describing which are the conceptions of genetic information from Biology teachers in training and how these conceptions changed through scientific and philosophical conversation sessions. We collected data using questionnaires, group interviews and individual representations. We identified that teachers in training comprehended genetic information in metaphorical terms, moved forward to a complete rejection of the metaphor and reached a balancing point in the end, exhibiting comprehensions compatible with the proposed scientific concept, although some showed a combination of different conceptual profiles.

KEYWORDS: Biology Teaching. Science Teaching. Information. Metaphor. Language.

RESUMO: *O conceito de informação genética é de relevância para a compreensão de problemas socioambientais, como organismos geneticamente modificados e terapia gênica. Levando em consideração a possibilidade de esse conceito causar distorções conceituais por metáfora na aprendizagem, objetivamos descrever quais são as concepções de informação genética de professores de Biologia em formação e como suas compreensões foram modificadas ao longo de reflexões científicas e filosóficas. Coletamos dados por meio de questionários, entrevistas em grupo e representações individuais. Identificamos que professores em formação compreendiam a informação genética em termos metafóricos, avançaram para uma rejeição completa da metáfora e atingiram um ponto de equilíbrio no encerramento, exibindo compreensões compatíveis com o conceito científico proposto, apesar de exibirem uma combinação de perfis conceituais. Propusemos critérios linguísticos para utilizar a metáfora no ensino e para identificar o uso denotativo do termo. Oferecemos um quadro de assertivas para diagnóstico de concepções e indicamos implicações didáticas.*

PALAVRAS-CHAVE: *Ensino de Biologia. Ensino de Genética. Informação. Metáfora. Linguagem.*

RESUMEN: *El concepto de información genética es importante para el discernimiento de problemas socioambientales, como los organismos genéticamente modificados y la terapia génica. Habiendo en cuenta la posibilidad de que este concepto provoque deformes conceptuales por metáfora en el aprendizaje, nos proponemos describir cuáles son las concepciones de la información genética de los profesores de Biología en formación y cómo se han modificado sus conocimientos a lo largo de las reflexiones científicas y filosóficas. Los datos se coleccionaron a través de cuestionarios, entrevistas grupales y representaciones individuales. Identificamos que los docentes en formación entendían la información genética en términos metafóricos, avanzaban hacia un rechazo total de la metáfora y lograban un punto de equilibrio al final, exhibiendo comprensiones compatibles con el concepto científico propuesto, a pesar de exhibir una combinación de perfiles conceptuales. Propusimos criterios lingüísticos para el uso de la metáfora en la enseñanza e identificar el uso denotativo del término. Ofrecemos un marco de aserciones para el diagnóstico de las concepciones e indicamos implicaciones didácticas.*

PALABRAS CLAVE: *Enseñanza de Biología. Enseñanza de Genética. Información. Metáfora. Lenguaje.*

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Introduction

Education related to Science, Technology, Society and Environment (CTSA) aims to improve scientific literacy. In this sense, it guides curricular content and procedures to enable the learning of topics that contribute to making better decisions regarding nature and socio-environmental problems (RICARDO, 2007; SANTOS; MORTIMER, 2000; SASSERON; CARVALHO, 2011). In this approach, socio-environmental problems are the learning contexts, while scientific and technological concepts constitute the reference knowledge (SANTOS; MORTIMER, 2000).

One of the most important topics in Biology is the Teaching of Genetics, an area that helps to position students on issues such as: genetically modified organisms, DNA and RNA vaccines, gene therapy, gene editing and evolutionary theory itself. Among the concepts necessary for the interpretation of these decision-making scenarios is the concept of *genetic information*. Despite the relevance attested by the wide occurrence of the term in teaching materials, there is a lack of consensus regarding its definition in the philosophical and scientific debate (GANIKO-DUTRA, 2021). At the same time, we indicated the possibility of this term causing conceptual distortions due to it possibly being connotative in nature. To avoid conceptual distortions and, therefore, ensure that students have access to more precise terms, we propose an investigation into the conceptions of Biology teachers regarding the term *genetic information*.

Thus, considering that the concept of *information* is a reference knowledge for understanding and confronting the socio-environmental problems mentioned above, this work's initial objective is to diagnose the previous conceptions of *genetic information* currently disseminated by undergraduate students in Biological Sciences. A second approach showed how these undergraduates' understanding of the topic became more precise throughout the proposed activities, in order to clarify the concept from scientific and philosophical points of view. Finally, we propose a reflection on the thought-language relationship of a metaphorical nature and the undesirable conceptual distortions they bring.

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The concept of *genetic information*

The word *information* is one of the fundamental principles of Biology, being an important structuring concept for this science. According to Scheiner (2010), it can be summarized in the statement: "life requires a system to store, use and transmit information". In this context, the most evident expression of the presence of the word *information* in biological phenomena occurs in the areas of Genetics and Molecular Biology.

Despite its evident importance, this concept has been widely discussed from different epistemological points of view, however, without apparent consensus. Without the aim of deepening the discussion at this time, we indicate part of the diversity of approaches that exist for interpreting the concept: (I) causal information (GODFREY-SMITH, 2008; SHANNON, 1948); (II) semantic information (GODFREY-SMITH, 2008; MAYNARD SMITH, 2000; SHEA, 2007; 2011; STEGMANN, 2004); (III) reified information (WILLIAMS, 1992); (IV) transmissive information (BERGSTROM; ROSVALL, 2011; GODFREY-SMITH, 2011; MACLAURIN, 2011; STEGMANN, 2014); (V) evolutionary information (KOONIN, 2016); (VI) fictitious information (LEVY, 2011); and (VII) signaling games (PLANER, 2014).

Within the scope of Genetics, we identify at least the following four meanings relating to the term *information*, which characterizes polysemy (GANIKO-DUTRA, 2021). These are references: (1) to molecular data, such as structure and quantitative measurements; (2) nucleic acids; (3) signals from the environment that interact with nucleic acids; and (4) scientific practice. As the term can also derive from a possible *metaphor* (GANIKO-DUTRA, 2021), it will be used in the sense of: (a) a process that establishes a correspondence relationship between two objects; and (b) the reported object.

Most authors conceive the term *genetic information* based on a thought-language relationship, but some, such as Levy (2011) and Maturana and Varela (2001), consider it as a metaphor. Levy (2011) even proposes its elimination in Biology due to the lack of semantic plausibility to designate evolutionary functions, remaining valid only for proximal explanations. Despite postulating the evolutionary dimension of information, when questioning its effects on organisms, the explanations are often physiological (*idem*). His criticism also draws attention to the intentional nature of the term, and even to the tone of the explanations in which it occurs, often accompanied by quotation marks.

Maturana and Varela (2001, p. 218) state that there is no "transmitted information" in Biology, indicating that this interpretation is conceived based on the metaphor that communication is a tube: "communication is something that occurs at a point, it is taken through

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a conduit (or tube) and delivered to another end, the receiver" (sic!). According to Levy (2011), the characteristics of informational descriptions are: directionality, since there is a sender that sends an intermediate factor to a receiver; the correspondence between distinct parts of two systems; and the agency of transmitters and receivers to the detriment of the passivity of the signal (information).

Despite the importance of metaphors for understanding the molecular phenomena that occur in cells, it is argued that their use requires care so as not to fall into metaphysical views that reify information, as well as gene-centric views (LEVY, 2011). Furthermore, Maturana and Varela (2001) reject the use of this metaphor, which would indicate that the interaction would be determined by the sender and not by the structural dynamics of the coupling system. In the metaphor, the receiver would be conceived as a passive entity that only receives the information sent by the sender. However, the authors argue that the effects on the receptor are related to its structural characteristics, that is, how the perceived information reverberates in the flow of matter and autopoietic energy that constitutes it.

Thought-language relationship and conceptual distortions in Biology Teaching

In the context of language, which also structures our view of the world (EVANS; GREEN, 2006; VYGOTSKY, 2000), metaphor occurs when we understand one concept in terms of another (LAKOFF; JOHNSON, 2003). We can say that there is a domain X, familiar and already known, and a domain Y, to be known. As X and Y have compatible aspects, we can understand Y in terms of X. In this sense, it is possible to affirm that the metaphor highlights compatible aspects between the domains, but hides incompatible aspects (LAKOFF; JOHNSON, 2003).

Metaphors originate from our experience, such as the notion of space and physical actions. Our current culture admits, for example, that time is organized according to a spatial dimension, with the future oriented "forward" and the past "backwards". In addition to these specific issues, metaphors structure our perception of reality (LAKOFF; JOHNSON, 2003).

With regard to metaphor in the context of Biology Teaching, Wandersee, Fisher and Moody (2000) presented a scheme about the apprehension of concepts in Biology. Among the sources of information are: the perception of the living world; society and culture; and formal and informal learning, which also includes metaphors. According to them, the means that students have to learn are: the acquisition of knowledge; organization and reflection; and the

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use of knowledge. These steps are fed back, and the resulting understanding can influence the way reality is perceived.

Our research group has been investigating how the use of connotative terms can lead to conceptual distortions in Biology Teaching. Although analogies and metaphors constitute a relatively common teaching resource for understanding the most fundamental characteristics of nature, they also bring some degree of associated conceptual deformation. Therefore, the transfer of incompatible aspects between two domains associated by a metaphor configures conceptual distortion by metaphor (CESCHIM; GANIKO-DUTRA; CALDEIRA, 2020).

In this sense, when we reflect on the use of metaphor in teaching (GLYNN, 2007), it is possible to explain it through another metaphor. Using them in teaching is like scaffolding. Just as this instrument is used to construct a building and removed after the work, the metaphor can be used to teach, but needs to be removed as soon as learning is diagnosed, in order to avoid transferring incompatible aspects from one domain to another. A discursive template for using metaphor in the classroom could be: "just as X [describes the compatible aspect of the familiar concept], Y also [reinforces the compatible aspect of the concept to be taught]. However, although X [describes an incompatible aspect of the familiar concept that cannot be transferred to the concept to be taught], the same phenomenon does not occur for Y".

Methodology

This investigation, of a qualitative nature (PATTON, 2002), was conducted within the paradigm of the vision-logic of interpretative research advocated by Taylor (2014).

Data were collected through questionnaires and interview guides applied to undergraduate students of the Biological Sciences course at a state university in the state of São Paulo, both full-time and night-time. In this sense, fifteen meetings were held between June 2022 and January 2023, with an intentional sample, with the aim of diagnosing how the undergraduate students' approach to topics related to Molecular Genetics evolved. The investigation was carried out in accordance with the ethical guidelines of the National Health Council with approval from the Research Ethics Committee.

During the meetings, recorded group interviews were carried out according to the discursive movements proposed by Windschitl, Thompson and Braaten (2018). We also administered an initial questionnaire and a final questionnaire, the answers to which were submitted in writing.

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According to the objectives, the meetings were divided into three moments: (1) the initial stage (three meetings), when we problematized the epistemological issue and delivered the initial questionnaire, (2) the development (nine meetings), when it was proposed to read a Buckland (1991)[4] and responses to the initial and (3) closing questionnaire (three meetings) were collected, at which time participants also responded to the final questionnaire and explained their own representations on the topic.

The initial questionnaire was divided into two sections, so that the questions in the second section did not influence the answers in the first. The first section featured the following command:

> Nucleic acids (DNA and RNA) are essential molecules for maintaining the organism's homeostasis, for the maintenance of the species over time, and are involved in several molecular processes in the cell. Explain the function and functioning of nucleic acids in living organisms.

As expected, based on our initial hypotheses, that there would be a profusion of the use of the word *information* in the answers (such as "transmission of genetic information"), the topic gave rise to a development in the second section. From this perspective, the word *information* can be understood as a unit of communication. When we inform, we are informing someone about something. Therefore, the second section of the form presented the following questions:

- Who would be communicating, that is, who would be the sender?
- Who would be communicating to, that is, who would be the receiver of the message? It is
- What would be being communicated, that is, what is the nature of this information; What would it be about?

Among the activities carried out in the set of meetings that we call *development*, we can mention: epistemological discussions, reading of articles[5], elaboration of individual representations, analysis of the responses collected in the initial questionnaire and analysis of the transcript of the second meeting.

In the *closing* stage, a prior definition of the word *information* was proposed to reflect on the relevance of its use in Biology (GANIKO-DUTRA; CALDEIRA, 2022). This proposal was not presented as a scientific consensus to the students, but rather as a "living science", that is, as an issue that is still under debate in the scientific community. It was also proposed to study

[4]This reading contributed to an initial mapping of the discussion about the *information* present in the area of Information Sciences and Natural Sciences.
[5]Barbieri (2019); Buckland (1991); and Capurro and Hjorland (2007).

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a case of mimesis observed in the *Boquila plant trifoliata*[6] and, finally, the final questionnaire was applied, the results of which were interpreted according to the Likert scale. Among the statements present in this instrument, we selected those related to *metaphor* (table 1).

Table 1 – Assertions for data collection in the final questionnaire. The answers were structured according to the Likert scale, with four options based on justification in case of disagreement (completely agree, partially agree, partially disagree and completely disagree)

<table>
<tr><th>Assertive</th><th>Would the students have understood that...</th><th>Possible conceptual distortion</th></tr>
<tr><td>A) Genetic information can be transmitted from an organism to its descendants (incorrect).</td><td rowspan="2">Don't the biochemical reactions of living beings send information? Do living beings synthesize molecules, emit patterns of energy and waves that are eventually perceived by other organisms? Would they be aware that this process is not directed or intentional, but established only by evolutionary contingencies?</td><td>From an evolutionary point of view, there would be a transmitter of genetic information.</td></tr>
<tr><td>B) There is no transmitter for the genetic information that is translated into (correct) protein synthesis.</td><td>From a physiological point of view, there would be a transmitter of genetic information.</td></tr>
<tr><td>C) Organisms receive genetic information from the (incorrect) parental generation.</td><td>Are the living beings themselves or their cells that interact with the surrounding matter and energy, establishing internal or external correspondences, of a material or energetic nature? Occasionally, such elements were produced by other organisms, or are their continuation.</td><td>From an evolutionary point of view, there would be a receptor for genetic information.</td></tr>
<tr><td>D) The cell is the one that receives the (incorrect) genetic information.</td><td>Is codon matching in amino acids a metabolic emergency of the cell?</td><td>From a physiological point of view, there would be a receptor for genetic information.</td></tr>
<tr><td>E) Genetic information is nothing more than the nucleic acid molecules themselves (incorrect).</td><td>Nucleic acid sequences do not represent anything, but are just molecules? The sophisticated patterns and processes in which they are involved are complex products that have resulted from biological evolution.</td><td>Molecules would carry meaning.</td></tr>
<tr><td>F) A bird can make a sound with the intention of warning the flock that there is a predator in the area (incorrect).</td><td rowspan="2">Is communication between living beings an unintentional evolutionary emergence that arises from contingent interactions?</td><td rowspan="2">There would be intentionality in the communication processes between living organisms.</td></tr>
<tr><td>G) The female gametophyte of bryophytes sends a chemical signal in order to attract the antherozoid (incorrect).</td></tr>
<tr><td>H) A toxin molecule can be interpreted by a cell as an inhospitable environment (incorrect).</td><td>Do response patterns to environmental information occur through unintentional chemical, physical or biological interactions devoid of cognition?</td><td>There would be a cognitive interpretation in biological phenomena.</td></tr>
</table>

Source: Prepared by the authors

[6]This plant is capable of mimicking the leaves of other plants close to where it grows. The purpose of the discussion would be to interpret mimesis based on the concept of *information*.

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The data were selected from the transcription of the most representative excerpts from the meetings, when participants explicitly discussed the concept of *information*. At this stage, the data was anonymized.

We then undertook a thematic analysis with inferences made based on the authors' creative synthesis (PATTON, 2002). In this sense, we identified three categories of meanings on the part of students: *i*) conceptual distortions of a thought-language relationship nature (CESCHIM; GANIKO-DUTRA; CALDEIRA, 2020); *ii*) conceptual distortions of an epistemological nature (*ibidem*); and *iii*) understanding compatible with the scientific concept. In this article, we will analyze category *i*, which concerns *metaphor*. We use indicators to delimit units of meaning and categorize conceptions. The indicators were *sender*, *receiver*, *send*, *receive*, *transmit*, *pass* and *interpret*.

Results and discussion

We will describe the students' conceptions (E), identified in the thematic analysis for the *metaphor category*, in each of the three moments: initial stage, development and closure.

To answer the first question of the initial questionnaire, five of the six respondents used the word *information*, and all used words indicative of conceptual distortion. Student E2 responded as follows:

- The function of nucleic acids is related to the storage and transfer of information from organisms, they are the master code ("the cake recipe") of each individual.

There we can identify the word *transfer* as an indicator of conceptual distortion by metaphor. However, the same students who exhibited indicators of distortion provided explanations compatible with the scientific concept:

> Its operation consists of promoting, through its information, the synthesis of proteins that act in the maintenance of life. (E2)

Furthermore, all students indicated senders and receivers for genetic information, which, in itself, consists of indicators of conceptual distortion by metaphor. The sender was identified as the organism (E1), the genetic material (E2 and E5), wherever the information is (E3), the mother cell (E4), and the cell nucleus (E7). The receptor was identified as being the organism itself (E1, E2), the environment that the genetic information influenced (E3), the daughter cells

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(E4), the cells (E5) and the RNA (E7). Levy (2011) considers the metaphor of genetic information as a flexible communication process, which can explain the notes of different senders and receivers, according to different contexts and points of view.

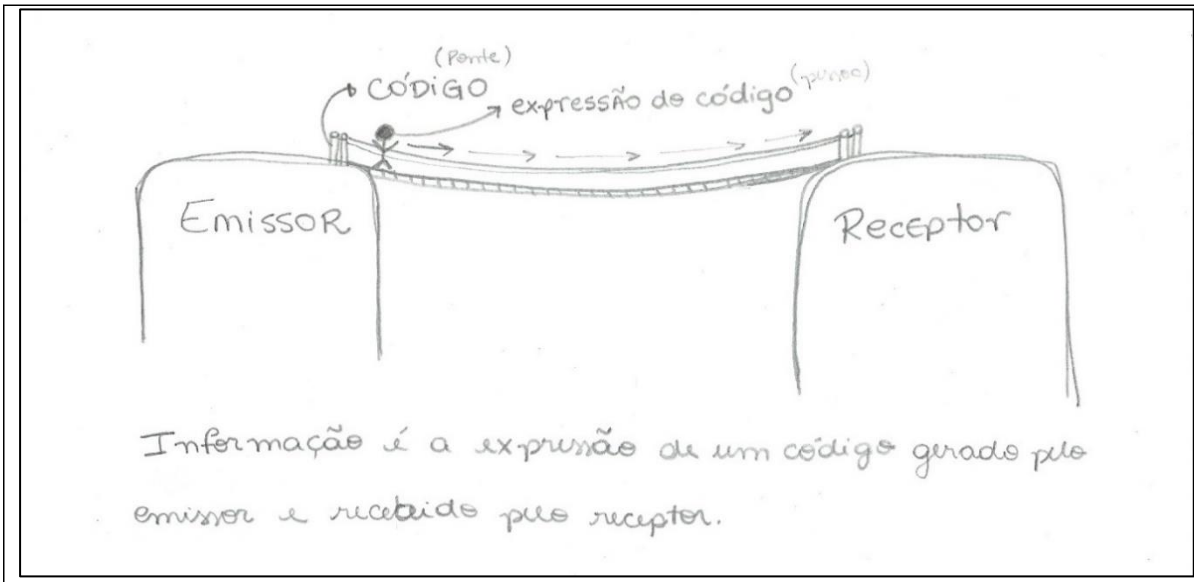
Throughout the discussions in the initial meetings, the students spoke structured based on metaphors, as in the following statements.

- The information, in my opinion, depends on who is issuing it and who is receiving it. (E2);
- Making an analogy with sound propagation, there must be a medium for this propagation, so information would not be the medium, it would be the sound. It would be what is propagated. (E1); It is
- I want to think about the information from one cell trying to send something to another. It has an objective and then the receiver, in his subjectivity, will receive it in different ways. (E2).

In the latter, the word *objective* leaves an explicit connotation of intentionality.

In individual representations, E2 represented genetic information as an intermediate factor between sender and receiver (illustration).

Figure 1 – Representation of the concept of genetic information produced by student E2



Legend: Emitter, Code (Bridge), Code Expression (Person), Receiver/
Information is the expression of a code generated by the emitter and received by the receiver.

Source: Prepared by E2. Authors' collection

At certain moments, it was possible to identify responses whose concepts oscillated between connotation and denotation, such as those transcribed below.

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- There is the fact that it can be an object, an event; there is information that is the means; and there is you assimilating this, who is the receiver. So, the fact or object is not the same thing as the process of transmitting it. (E1)
- If it doesn't have an interaction with another organism, it's not information, it just is. (E4)

In this dialogue, it is possible to observe the replacement of the word *emitter* by *object*, indicating a possible transition from metaphor to denotation.

Throughout the development, it was possible to notice students' linguistic conflicts when searching for other alternative words to the metaphor. This was the case, for example, of student E6 when asked about the definition of *genetic information*:

- Determination of transmittable characteristic implies that I am referring to the characteristic, but I want to refer to the determining factor, so I think I would change it to "transferable determinant".

Still at this stage, it was possible to observe an increase in the use of scientific terms, for example, in the following statements:

- I think it would be the sequence of nitrogenous bases combined into amino acids. (E1);
- Correspondence. (E6);
- So expression is transcription, from DNA and RNA. (E6)

In addition to opting for more precise terms, students showed a tendency to reject the word *information*. When asked to describe the structure and functioning of nucleic acids, the same task requested in the first meeting, none of them used the term *genetic information* in their individual representations. Previously, five out of six participants had used this expression. E2, for example, who in the initial stage had responded based on a metaphor, presented the following definition:

> The functioning of the genetic material, contained in the nucleus, occurs through the processes of transcription and translation of the base pairs that form the strand into protein units, which later (together) may act on the physiology and morphology of the organism as a whole.

We consider this change as a sign of the "fear of metaphor", as described by Lakoff and Johnson (2003).

At times, the rejection of terms related to *information* led students to use it as a synonym for "genetic material", neglecting the meaning of *correspondence*, intrinsic to this fundamental principle of Biology. In this sense, it was possible to observe statements such as:

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- DNA is genetic information. (E1);
- We find genetic information as a synonym for genetic material, or anything inheritable. (E6);
- The idea would be to replace terms synonymous with set of genes, then use terms such as genotype, translation and transcription. (E3).

As long as it is properly used in classrooms, we consider the metaphor to be an important resource for Biology Teaching, as proposed, among others, by Ceschim, Ganiko-Dutra and Caldeira (2020) and Glynn (2007). Therefore, it is not desirable for students to acquire an aversion to metaphor, but, on the contrary, we propose that from an epistemological deepening of biological knowledge, they are able to develop pedagogical knowledge of the content (SHULMAN, 1986) sufficient to determine the limits the use of metaphor in teaching. To do this, it is important that they are able to distinguish the terms: *communication as a tube*, *genetic information* and *genetic material*.

In one of the meetings, the group of students came close to a consensus that the term *genetic information* could be reduced, without risk of losing meaning, to *genetic material*. However, genetic information cannot be taken as synonymous with DNA and RNA. Information consists of the triadic relationship between two objects and the correspondence between them. An intervention by the researcher when asking them "What is the function of DNA?" made them rework their conceptions and reach the idea of correspondence.

At the end, it was possible to observe that the students began to be more careful when using informational terms, associated with the idea of correspondence, as indicated by the following statements:

- I was thinking that the information is directly linked to the correspondence. (E3);
- If you put your hand on something hot, there is a correspondence between the hot thing and the impulse it generates, and there is the information that will only run in the nervous system, which is the information about the stimulus and the action you have to do, which in this case is the reflex arc. I have the impression that in this case, we have two pieces of information, because there are two correspondences, right? There is a correspondence between the object that generates the stimulus, and the stimulus and the consecutive action. (E1).

The evidence indicates that the meetings allowed students to go through the three stages of conceptual understanding of Biology: knowledge acquisition (initial stage and learning experiences external to the context of this research, experienced in the course), organization and reflection (debates mediated by the researcher and metacognition) and application of knowledge (interpretation of phenomena and previous conceptions) (WANDERSEE; FISHER; MOODY, 2000).

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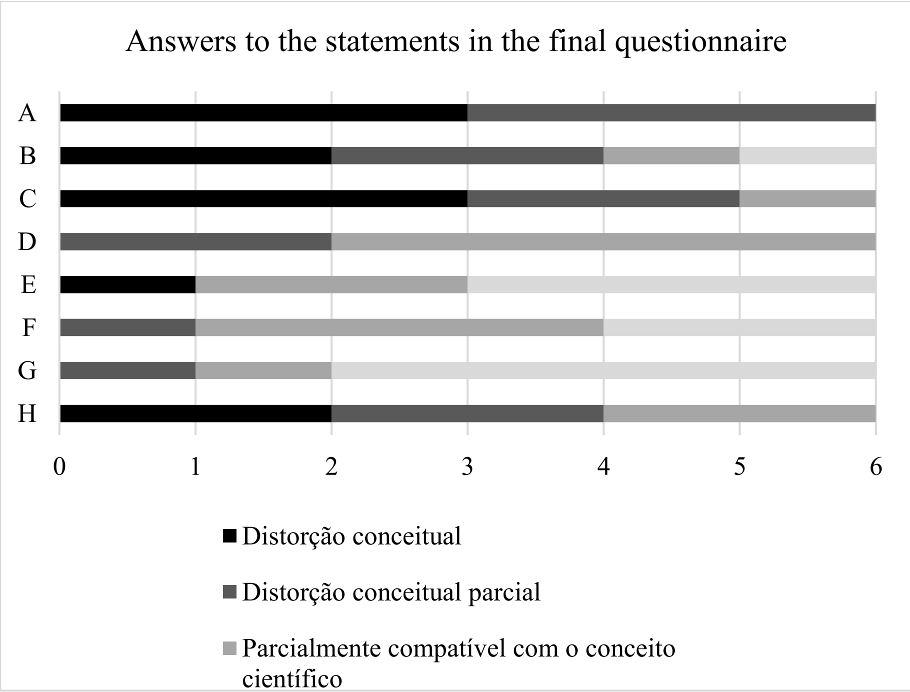
Despite identifying a "balance point" in the use of the term *genetic information* ─ which is between the metaphor, which represents an exaggeration in attributing incompatible aspects to the information; and between the reduction, which removes correspondence as an important essence of the concept ─, the students also exhibited mixed conceptions, in which they expressed, at the same time, conceptions compatible with the scientific concept and metaphorical, as was clear in E4's speech.

- I kept thinking that when I looked at the tree, I was receiving that information and then I thought of some other animal seeing it as an obstacle. He is the receiver because he is interacting and receiving this information, but he is also perceiving why there is correspondence formulating this information, processing it, right?

At the same time that there are indicators such as the terms *correspondence* and *interacting*, we can identify scars of metaphorical thinking, as indicated by the words *receiving* and *receiver*.

The answers to the final questionnaire with the respective quantifications of the statements can be found in the following graph.

Graph 1 – Responses to the final questionnaire, indicating the number of statements marked in each option on the Likert scale. The x-axis corresponds to the number of respondents and the y-axis corresponds to the statements indicated in table 1



Legend: Conceptual Distortion / Partial Conceptual Distortion / Partially Compatible with Scientific Concept

Source: Prepared by the authors

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The statements that described *information* in metaphorical terms, using words such as *emission* and *receiver*, were those that most contributed to the conceptual distortion by metaphor (A, B, C and D). The students were able to identify the teleological inconsistency in statements F and G, indicating the absence of conceptions that explicitly refer to intentionality.

Such results suggest one of the following hypotheses: *i*) there are conceptual profiles (MORTIMER; SCOTT; EL-HANI, 2011) related to the concept of genetic information, being the profile that structures the interpretation of phenomena through metaphor and the profile that interprets the from correspondence; or *ii*) students did not have enough learning experiences to progress from connotation to denotation. In this sense, it would be important for this investigation to continue in order to verify whether it is possible for students to reach a level of learning in which they only provide evidence of learning with indicators of the scientific concept.

Carvalho, El-Hani and Nunes-Neto (2020) suggest a reorganization of the Biology curriculum for High School that prioritizes the structuring concepts of this science. Since structuring concepts bring more cognitive benefits than simple memorization, we agree with the proposal, as long as it is aligned with the objectives of CTSA Education. In fact, the acquisition of structuring concepts allows for a cognitive reorganization that integrates students' prior knowledge, offering a new, more comprehensive and less fragmented interpretation.

In this sense, teaching *information* as a fundamental principle of Biology is potentially integrative, as it will allow students to grasp a new interpretation of the phenomena covered in the study of life sciences. Based on the scheme proposed by Ganiko-Dutra, Ceschim and Caldeira (to be published), through teaching the concept of information, it is possible to integrate knowledge from different levels of organization (molecular, organismic and population) in different time frames (physiological, ontogenetic and evolutionary).

Final remarks

Based on the understanding of *information* as a fundamental principle of Biology, the mapping of conceptual distortions by metaphor mobilized for conceptual understanding, and taking into account the integrative potential of this concept, we list some didactic developments.

Strategic and planned discursive movements are a valuable resource for providing learning experiences so that students have the opportunity to confront and reflect on metaphorical conceptions and reconstruct their own understandings. In this sense, the

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systematization proposed by Windschitl, Thompson and Braaten (2018) is a great contribution to the Biology teacher's repertoire.

Although the use of metaphors can generate conceptual distortions, their value as a teaching resource should not be discarded. As long as the teacher has pedagogical knowledge of the content, it is possible that the metaphor contributes to learning the concept of *information* by explaining the notion of correspondence. However, once the teacher diagnoses the sedimentation of learning, it is also necessary to make explicit the incompatible aspects of the metaphor, for example, intentionality.

An important step in learning is to differentiate: *genetic material*, *information* and *communication*. It is possible for students to mix these three concepts, which are incompatible. In this sense, it is pertinent for the teacher to distinguish between them. By this, we mean that teaching about the structure and functionality of nucleic acids is not enough to learn the concept of *information*. However, it is through the teaching of scientific concepts specific to Biology that structuring concepts can be taught (CARVALHO; EL-HANI; NUNES-NETO, 2020). Thus, by teaching the structure and functioning of nucleic acids, teachers can also teach the concept of *information*.

With regard to the curricular structure of initial training courses in Biological Sciences, we consider that the concept of *information* can be present at different times: 1) in the Philosophy of Biology discipline, deepening the discussion and offering a space for integrating concepts; 2) in specific subjects of Genetics, Molecular Biology, Cellular Physiology, Evolution, Ethology, among others. In undergraduate courses, this concept can still be explored in teaching practice subjects, as a possibility for teachers to organize classes using *information* as a reference knowledge to face socio-environmental problems; as well as being an integrative axis that organizes Biology content in Basic Education.

In this research, we seek to offer criteria for teaching Genetics by pointing out unwanted words, as they are a metaphorical use of language; criteria to identify a denotative use of the word information as a synonym for correspondence, offering a framework of assertions for diagnosing conceptions; and indicating didactic implications. We hope that these records will contribute to Genetics Teaching and citizen training to participate in decision-making related to socio-environmental problems involving scientific and technological issues.

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