Metaphor and narrative for effective and inclusive learning in science education

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Abstract

The project that will be presented in this paper concerns the use of metaphors and narrative in science education. The need to support science literacy in an inclusive manner has been affirmed and reiterated in the most recent European programs for research and innovation (Horizon 2020, Horizon Europe). The "Italian National Guidelines for the curriculum of preschool and first cycle of education" also emphasize the need to support the connection of humanistic and scientific culture and to orient learning towards the acquisition of key competences. In order to achieve these aims, educational practices based on interdisciplinary studies have been designed and improved, especially in STEM education.

In this paper, we present the essential theoretical assumptions and the most important results of the project "Knowing through metaphors". The project is an exploratory survey designed through interdisciplinary planning aimed at empirically testing the hypothesis that metaphors foster the acquisition of scientific knowledge. The narrative-metaphorical mode, in the context of the exploratory survey, led to the acquisition of more complex, longer-lasting, more evenly distributed knowledge with positive effects for the development of autonomy-oriented skills.

1. Premises of the research

The project "Knowing through metaphors" that is to be presented in this paper concerns the use of metaphors and narrative in science education. Over the past few decades, philosophers, psychologists, anthropologists, linguists, and scholars in the field of education, have offered insights into the fundamental role of both narratives and metaphors. They are in fact considered fundamental instruments used by human beings to think, perceive, imagine, learn, and make sense of their experiences. Metaphor and narrative perspectives, nevertheless, have mostly been utilized separately.[1] Today, growing interest in STEAM education makes it possible to promote the connection beetween metaphor and narrative as a strategy for effective and inclusive science education. In pursuing this objective, this strategy might help to realize the inclusive dissemination of science literacy as a focus of European research and innovation programs (Horizon 2020, Horizon Europe).

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[1] The project undertaken by Michael Hanne since the 1990s and named "Narrative Metaphor Nexus" is a pioneering work in this field: symposia and conferences were promoted on how narrative and metaphor function in disciplines and professional domains such as medicine, politics, law, education (Hanne, 1999; Hanne, 2011). The Center for Metaphor and Narrative in Science, which is hosted by the Department of Education and Humanities of the Modena and Reggio Emilia University, similarly aims to promote multi- and inter-disciplinary research relating to the role of metaphor and narrative in science communication, science education, and mathematics (cf. Fuchs 2007, 2015, Corni et al. 2018, Corni et al. 2019, Contini, Giuliani and Manera 2020). In 2017, some members of the center presented their recent research at "Look Both Ways: Narrative and Metaphor in Education", the fifth conference in Hanne's series, which took place at VU University in Amsterdam (Fuchs et al. 2018; cf. Contini 2020a, p. 12).

The *Science with and for Society* programme in Horizon2020 included the promotion and dissemination of science literacy as conditions to face the challenge of connecting science to society by making science education and careers attractive for young people. Based on the achievement of the program, final recommendations stated the necessity to further improve invest in science education for all as a condition to ensure excellent Research and Innovation to tackle the challenges of today for a better future (European Commission 2020).

Today, Horizon Europe has implemented the recommendation from Horizon 2020 to promote science education mainstreaming in projects across the new European program. Regarding science education as a standalone topic, the program states the need to develop a STE(A)M roadmap for Science Education in order to promote and improve scientific careers and a science-literate society. The need for science literacy and scientific training has definitely been enhanced by the COVID-19 pandemic, which has demonstrated the importance of Europe's scientists and doctors in keeping our society safe and healthy. Also, EU policies such as the European Green Deal, the Digital transition and Health call for more highly educated European scientists.

In the Horizon Europe program, the cluster "Culture, creativity and inclusive society" upholds the following goals with regard to education:

- to enhance interdisciplinary research for the construction of an aware and inclusive society and for the development of effective communicative and educational models;
- to promote the diffusion of scientific culture and science education as a condition for inclusive and sustainable social growth and for the opening of science to the needs of the community.

Even the Italian National Guidelines for the preschool and first cycle of education[2] (2012), consider science education to be a resource to develop responsible and proactive citizens: the learning objectives are defined and addressed according to the competences of the first cycle of education (in particular, with respect to the critical use of language and the development of autonomy, expressiveness, and responsibility)[3]. In addition, the guidelines reiterate the need to respect the principle of inclusiveness in education.

The project that this document presents is aligned with the premises and goals of the aforementioned European policy programming. "Knowing through metaphors" is meant to be an exploratory research project that aims to help establish criteria and operational approaches to define the impact of using integrated metaphors and narratives on the effectiveness and, consequently, the inclusiveness of science education. The research team that conducted the project shares the perspective that metaphor and narrative are an important resource for learning science concepts for two main reasons:

- they are resources for a learning process conceived as an interactive construction of knowledge rather than as reception and adaptation of predefined contents;
- they allow positive interaction between scientific and ordinary language, encouraging an attitude of complexity, the enhancement of the plurality of languages and the construction of relationships between different areas of experience

The inclusiveness of this educational strategy must be understood not so much as a goal, but rather as a consequence of its effectiveness for learning. According to the perspective shared by the research team, an effective strategy for learning science is necessarily inclusive: for an authentic understanding

[2] Preschool, elementary school and middle school.
[3] Cf. also Council of the European Union 2018.

of scientific concepts, it is necessary to make a plurality of languages interact and design cognitive pathways in continuity with students' prior experiences and knowledge (Amin 2015a, 2015b, 2020; Lancor 2014, 2015). Inclusivity relies on effectiveness because the plurality of languages involved and the constructive mode of learning is reflected in the ability to involve different individualities and different attitudes.

In the following paragraphs, the premises, the methods and the results of this exploratory research will be presented. The research focused on the use of metaphor and narrative in the teaching of biology and was carried out in a comprehensive school in Reggio Emilia. The research compared the learning outcomes of classroom groups that were involved in two different ways of explaining the same scientific content (the cell and its components): on one hand, the exposition of learning content through the introduction of scientific language and the definition of concepts; on the other hand, the construction of a narrative in which scientific content becomes the object of an "encounter" and is described through metaphorical associations. The objective of the comparison was to identify significant differences in the effects of the two types of lesson on students' learning. The researchers wanted to define indicators to support the claim that the combination of metaphor and narrative has specific cognitive value and can promote effective and inclusive learning.

Underlying this idea are well-established theses about the cognitive value of both metaphor and narrative, and a perspective on learning that considers knowledge and creativity to be closely linked. Regarding the cognitive value of metaphor, we refer primarily to Max Black's *interaction view* for its ability to justify both a cognitive and an innovative value of metaphor. Metaphor according to the interaction view is primarily a device that activates a variation of meaning or semantic innovation, understood as a variation in the application of a term (cf. Giuliani 2020, p. 178). This variation, according to Black's structural definition, is the result of the interaction between the meanings of - or systems of implications associated with - the terms that form the metaphor: the metaphoric interaction activates, by evoking them, these systems of implications and establishes connections that leads to a different reference of the term in question.[4] In this sense, metaphor is not reduced to a single word, but is the result of the interaction between two factors in the context of an entire sentence (Contini 2020b, p. 28).[5]

The aspect that characterizes the interactive metaphor, however, consists above all in the element of cognitive innovation: the fact that it induces those who understand it to construct a new system of implications with respect to the *normal* one (Black 1962, pp. 40-41). For example, the metaphor-wolf, by emphasizing certain aspects of man, organizes the idea of man and highlights new possible relations in reality. Black emphasizes the heuristic and innovative value of the interactive metaphor together: the two values cannot be distinguished, since the implications and associations that flow from the metaphorical meaning are determined by the interaction itself. From his perspective, to

[4] For example, it becomes possible to say of a man that he is a wolf because a connection is established between certain characteristics associated with the wolf and certain qualities of human behavior, which are evoked, precisely, by the interaction (thus, we can speak of human aggression as a predator trait).

[5] The premise of this conception of metaphor in Black is a philosophical perspective that considers vagueness a property of common language that guarantees its versatility. The vagueness of a word, for Black, "shows itself in producing borderline cases, to which it seems impossible both to apply and not to apply the term" (Black 1949, p. 30); it is what is indicated by the assertion that "situations are conceivable in which its [= the term's] application is doubtful". A term determined according to Black, thus with a defined meaning, has a margin of indeterminacy in the variation of its application. This indeterminacy, however, does not make the term the bearer of some deficiency, thus a term to be replaced with a more "precise" term (Giuliani 2020, pp. 177-178).

affirm the creativity of metaphors is to argue that "some metaphors enable us to see aspects of reality that the metaphor's production helps to constitute" (Black 1977, p. 454; cf. Contini 2018).

That justifies the affinity between the use of metaphors and the use of *theoretical* models in Black's *Models and Archetypes* (1962): their characteristic is that of transferring, to an unfamiliar field that one wishes to explore, a set of implications belonging to a more familiar or better organized secondary domain (Black 1962, pp. 230-233). Black proposes Maxwell's example of the "imaginary incompressible fluid" as a model for the electric field that makes it possible to see and define its novel characteristics (Black 1962, pp. 226-228). The original domain is not simply illustrated by the secondary domain, but undergoes a restructuring from which new hypotheses and connections emerge (cf. Contini 2016, p. 27). The model actually "shows" something unseen in the previous perspective, and so the metaphor refers to something that has no definition outside the interaction (cf. Giuliani 2020, pp. 191-193).

Models and Archetypes started a series of successful studies that further investigated the function of models in science and their relationship with metaphors. Continuing the same investigation, Mary Hesse (1966) proposed her idea of the scientific model as a tool for redescription. Black's argument was also taken as a basis by Ricoeur in 1975 to support the constitutive value of the use of imagination in scientific knowledge. Moreover, starting from Black's studies on metaphor, in the Seventies a transversal debate arose in different fields of study, with the participation of important authors, as emerges in the influential collected volume *Metaphor and Thought*, which first appeared in 1979 edited by Andrew Ortony. Among others, the volume collected essays by Boyd and Kuhn, who undertook a confrontation on the role of metaphor for scientific explanation and discovery, as part of a debate on the epistemology of science, theoretical language and discontinuity between theories. Moreover, Black's notion that metaphor operates via an inter-domain connection became one of the crucial assumptions of the psycholinguistic approach to metaphor, from Lakoff and Johnson's conceptual metaphor theory (1980) to Gentner's structure-mapping hypothesis (1983), to Tourangeau and Sternberg's domain interaction hypothesis (1982), and to Glucksberg and Keysar's definition of metaphors as class-inclusion assertions (1993; Contini 2020a, p. 12).[6]

Similarly, in the Seventies narrative became the focus of many studies in the field of cognitive psychologists and artificial intelligence researchers.[7] It emerged that "many adults and children seem to use their knowledge of the structural features of narratives to understand and remember stories and to anticipate forthcoming information" (Contini 2020a, p. 10). The results of these studies recall Jerome Bruner's (1986) still relevant theses about narrative as a means by which agents construct their knowledge of the world around them, their understanding of themselves, and their communicative interaction.[8] Subsequently, since the mid-nineties, a new wave in narrative theory has focused on the cognitive basis of creating and understanding stories. Narrative analysts have shown that quite complex linguistic and cognitive operations are required to generate or comprehend even the most minimal stories and text in turn can force readers to modify the interpretative models on which they have hitherto relied (Emmott 1997, Margolin 2003). Moreover, narrative itself has been studied as an instrument for sense making and for the exercise of cognitive abilities.

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[6] See also the contributions collected in Gibbs (ed.) 2008.

[7] Cf. Kintsch, 1977; Mandler and Johnson, 1977; Stein and Glenn, 1979.

[8] For Bruner (1986), narrative is a specific "mode of knowing" which deals with the intentionality of human actions (*what* and *why*?) and the context in which these actions took place (where and when?). From the narrative perspective, truth is to be approached as situated or contextual (cf. Contini 2020a, p. 11).

Regarding the cognitive value of metaphor, in order to reinforce the relevance of Black's theory, the research took into account more recent developments in conceptual metaphor theory. The original core of Lakoff and Johnson's theory is the claim that "our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature" (1980, p. 3). Basic conceptual metaphors are cognitive structures by which we unconsciously organize and categorize our experience. They are living metaphors in the sense that they play a central role in defining our everyday realities (Lakoff and Johnson 1980, p. 55; Contini 2020a, p. 10). The theses, debated over the years by Lakoff and Johnson, have found critic development in multidisciplinary and interdisciplinary studies that cross the fields of cognitive science, philosophy and linguistics, and communication[9].

Regarding the sense of the "creativity" of metaphor, Ricoeur's study on the "living" metaphor (1975, trans. 1977) remains an important reference for research, as it contributed to making the hermeneutic and phenomenological approach more incisive by opening it up to comparison with the theses of cognitivist scope. The hermeneutic approach, on the other hand, allows us to justify a close relationship between metaphor and narrative. For Ricoeur, both the effects produced by metaphor and by stories depend on semantic innovation. In the case of metaphor, we have the production of a new semantic pertinence through an impertinent attribution.[10] In the case of narrative, we have an intrigue which is the result of synthesis (Ricoeur 1983-1985, vol. 1). A new meaning is generated also because reading is a dynamic process which actively transforms the world of the reader as well as what is being read (Contini 2020a, p. 16).

The theoretical studies for which the contextual and communicative aspects are constitutive of the meaning of metaphor open a further avenue to deepening the relationship between metaphor and narration, if this is understood as a genre of discourse. In addition, the attention to the relationship with the narrative leads us to recover an aesthetic approach to metaphor as a "figure" that does not exclude, but rather integrates its cognitive value. The importance of aesthetic categories in dealing with metaphor emerges especially in studies dealing with the specificity of visual metaphor (Forceville 1996, 2006). Attention to aesthetic aspects also allows us to specify the meaning of the knowledge and creativity to which metaphor gives access.

Regarding the role of metaphor in science education, our references were the results of some recent research in the field of cognitive science and learning studies: in particular, Amin and Lancor's studies on metaphor as a resource for conceptual change and for the construction of complex knowledge. For the relationship between metaphor and narrative, the research was inspired by the idea that an interdisciplinary approach to metaphor and narrative analysis can help tackle problems, which seemed difficult to solve when metaphors and stories were studied as separate compartments (Contini 2020a, p. 9). Specifically, the research is based on the proposal to consider metaphor and narrative as cognitive tools (Egan 1997) and relational constructs: just as metaphor operates through a projection and connection between domains, similarly, stories allow those who tell them and those who interpret them to establish spatiotemporal connections between different regions of experience (Fuchs et al. 2018). Narrative comprehension also requires situating participants within networks of

[9] Cf., e.g., Lakoff and Johnson 1999, Johnson (1981, 1987), and more recently Fauconnier and Turner 2002, Gibbs 2006, Johnson 2007, Kövecses (2015, 2020), Steen 2008, Steen et al. 2010, Ruiz De Mendoza Ibáñez and Perez Hernandez 2011; Ervas et al. 2017, Prandi 2017. Cf. Ervas and Gola 2006; Contini 2018.

[10] For example, in the expression of Mallarmé "The sky is dead" the predicate "dead" is compatible only with individuals belonging to the category of living beings but metaphor gives rise to a new semantic pertinence on the ruins of the literal, producing sense from non-sense (Ricoeur 1977, p. 296; cf. Contini 2020a, p. 16).

beliefs, desires, and intentions. If metaphors stimulate the mind to construct a high-order connection between entities referred to, and consequently metaphors "are like bridges" (Beck 1987, p. 13), stories are like "a network of bridges or like a network of links" (Contini 2020a, p. 13).

This relational conception of metaphor and narrative is situated, more generally, in a perspective that recognizes a continuity between science and the ordinary understanding of nature based on the imaginative mode of representing experience. The narrative mode, in this perspective, is compatible with scientific explanation and does not constitute its "naive" alternative: the nature object of science can be thought of as populated by agents with whom we can interact and communicate. An idea of continuity between knowledge that justifies the value attributed to narrative also belongs to the research of Zabel, another reference point for our study. According to Zabel, similarly Amin's assertions about conceptual change, the student's prescientific knowledge cannot simply be replaced by scientific conceptions that contradict his or her way of making sense of reality. Zabel agrees with Bruner that narrative plays an important role in meaning-making because it is close to human experience and behavior: indeed, both in stories and in the interpretation of experience we trace reasons, rather than causes, and use normative patterns (Zabel 2015, p. 37). The conceptual shift that allows access to scientific explanation must be a bridge between narrative construction and explanation in more strictly scientific terms: faced with the difficulty of learning, the need is not to avoid imaginative understanding and anthropomorphism, but rather to "build a pathway" that relates the different modes of cognition (Zabel 2015, p. 35).

2. Planning the empirical research project

The intertwining of the narrative, metaphorical and scientific dimensions that characterizes the research we are presenting is the result of an interdisciplinary project that has involved scholars of aesthetics, science education and pedagogy belonging to the "Metaphor and Narrative in Science" research center at the University of Modena and Reggio Emilia.[11] The interdisciplinary projects already conducted by the research group in previous years and months have been an important premise for the design of the contents and objectives of the research[12]: in particular, a significant contribution was made by the research on the use of metaphors in the educational contexts of early childhood conducted in collaboration with "Reggio Children Preschools and Infant-toddler Centres - Institution of the Municipality of Reggio Emilia" and the international conference "Metaphor between education and scientific communication".[13]

The research group aimed to find empirical indications in favor of the hypothesis that the metaphoric-narrative mode favors the acquisition of complex knowledge through the development of skills such as: being able to handle articulated content, making new inferences and implications, and

[11] Prof. Annamaria Contini, Prof. Tiziana Altiero, Prof. Roberto Guidetti, Prof. Maya Antonietti, researcher Andrea Pintus, and research fellows Alice Giuliani and Lorenzo Manera were part of the research group.
[12] In particular, the project "A Festive Thought. Visual metaphors in children's learning processes" constituted an important premise for evaluating the metaphors proposed by the children. For more in-depth information on the contents of the project, see the catalogue of the exhibition "A Festive Thought. Visual metaphor in children's learning processes" (2021), edited by Claudia Giudici, Sara De Poi, Vea Vecchi, Annamaria Contini, Elena Corte, and published by Reggio Children srl.
[13] The international conference "Metaphor between education and scientific communication" took place in 2018 at the Department of Education and Human Sciences of the University of Modena and Reggio Emilia, under the scientific direction of Prof. Annamaria Contini and Prof. Elisabetta Gola.

activating new associations between different learning contents. A further aim was to evaluate the ability of the metaphorical-narrative teaching method to encourage the emergence of new questions, the medium-long term memorization of content and the original re-elaboration of content. Useful data were also collected to support the hypothesis that the teaching methods tested supported more effective learning processes even in the most fragile students. On the other hand, the first analysis of the data collected was carried out keeping the research question open and looking for significant regularities for the classification and interpretation of the data.

The research design was developed with consideration of the conceptual, linguistic, and communicative aspects that combine to determine the cognitive effectiveness of metaphors.

For the metaphor identification process, the research team adopted, with some clarifications, the generic definition of metaphor as "understanding and experiencing one kind of thing in terms of another" (Lakoff and Johnson 1980, p. 5), generally shared in the literature in empirical research on metaphor. We have also followed the CMT perspective by organizing linguistic metaphors around conceptual cores, while constructing the categories in a mostly inductive way. On the other hand, we have integrated the definition of metaphor with the concept of "interaction" between two different conceptual domains, which Max Black names *systems of associated commonplaces*, or *systems of implications* (cf. ch.1): the reference to interaction seemed effective to avoid excessive generality and at the same time maintain a balance between a linguistic and a conceptual approach in the criteria for metaphors identification. For the concrete identification of metaphors for quantitative and qualitative analysis, the general principles of the identification method developed by the research group of the University of Amsterdam were adopted, also taking into account references to Cameron (2003). In particular, we considered the following cases as identification criteria: a) a word is used metaphorically itself[14]; b) a word is a direct expression of a conceptual domain that functions as a source domain in a mapping that is explicitly expressed as some form of comparison (cf. Steen et al. 2010, pp. 768-71, my transl.). Based on these criteria, we looked for occurrences in which: a) a term has a contextual meaning different from its base meaning - according to ordinary usage or to vocabulary - without regard to the meaning actually attributed by the student; b) a comparison between two different objects is made to express meaningful concepts that count as indications of understanding.

In the qualitative analysis, we tried to identify the metaphors that can be considered more promising from the cognitive point of view, following Max Black's definition of "active" metaphor. Black defines an active metaphor as one that possesses "emphasis" and "resonance": the metaphor possesses emphasis if it is perceived to be actively metaphoric and therefore its focus is not subject to modification by the producer and the "receiver" is willing to pause to grasp its "implications", understood as what is "behind the words"; resonance, instead, is what the metaphor possesses when it "sustains a high degree of elaboration of implications"[15] (Black 1977, p. 440-441). The strong metaphor for Black possesses both of these aspects in a marked way and is the one that is best

[14] E.g., in "He defends his claims well": in this case, "the metaphorical meaning in use is defined as the indirect meaning of the word and arises from the contrast between the contextual meaning of a lexical unit and its more basic meaning, the latter being absent from the actual context but observable in others" (Steen et al. 2010, pp. 768-771).

[15] In this way Black brings back some qualitative aspects of classification to quantitative criteria: if in fact the emphasis measures with the degree of intensity of the metaphor the "seriousness" that distinguishes it from an ornamental and "passing" expression, the resonance measures as extension and articulation of implications, therefore as complexity, the particular "significance" of a metaphor.

described by the interactive conception. The strong metaphor thus understood is also a "creative" metaphor. Based on this definition, in our empirical research we attributed a creative aspect to metaphors that had at least two of the following characteristics: the semantic enrichment power of the projection, the presence of semantic conflict, the role of a model, the dual direction of interaction, originality (having regard to the difference between originality and creativity[16]).

As for the scientific and conceptual aspects, these were integrated into a narrative designed by the research team as a reworking of a pre-existing text, *Lo strano caso della cellula X: le avventure del Prof. Strizzaocchi* (2012).[17] The narrative was entitled "Welcome to Ellulandia!"[18] The fictional "world" that is visited by the protagonists of the story is intended to be a kind of model built to discover how the cell is made and how it works, an entity of which one cannot have direct ordinary experience. In addition to introducing the basic concepts to describe the characteristics and function of the cell, the narrative was intended to convey the overall idea of the cell as a universe-world and life as an open system.

With regard to metaphors, we report below some associations structured on the basis of this model and their articulations (see Tables 1, 2 and 3 below):

<u>The world of Ellulandia</u>	<u>Cell</u>
Frontier	Cell membrane
Chief	DNA
Inhabitants (with roles, professions)	Enzymes / organelles (with precise functions)

Table 1: analogical correspondences between "The world of Ellulandia" / "Cell"

<u>Fortress</u>	<u>Nucleus</u>
It's hosting someone very important	It encapsulates the DNA

[16] Cf. Kohl et al. 2020.

[17] The experience of the project "Little Scientists" of the University of Modena and Reggio Emilia, led by Prof. Tiziana Altiero (member of the research group) together with Prof. Federico Corni, provided important indications for the creation of the stories and the test-questions. We also consulted didactic texts open to the use of narratives and metaphors for learning the concepts of evolution and the structure of the cell (the themes chosen for our activities), as well as essays of a theoretical nature regarding the role of metaphor in science and its learning (cf. Corni, Giliberti, and Altiero 2015).

[18] In the story, the science teacher takes the young students to a special room in the school, where they find a microscope that becomes the gateway to a special world that can be visited with a submarine. While exploring, the children see many things happen and meet several characters, and as the teacher explains what is happening, they begin to understand the structure of the cell. Back in their classroom, they are able to see the world from a different perspective.

It is often surrounded by water	It is immersed in the cytoplasm
It has walls with passageways controlled by guardians	The nuclear membrane only allows recognized substances to pass through by opening or closing the pores of the nuclear membrane

Table 2: analogical correspondences between “Fortress” / “Nucleus”

<u>King/leader</u>	<u>DNA</u>
He knows what others have to do	Contains information for the functioning of the cell
Tell everyone what to do	Order which substances to synthesize
It holds a code with the laws-rules of the land...	The instructions are written in its nucleotide sequence
He is obeyed by everyone	Particles perform operations based on the information it contains.
He’s an important person and must reside in a safe place.	It’s inside the nucleus, which in turn is inside the cell.

Table 3: analogical correspondences between “King leader” / “DNA”

As far as the narrative dimension is concerned, the research was in continuity with the perspective that in the scientific literature is referred to as the *new wave of* narrative theory[19], which emphasizes the complex cognitive operations that are performed in the process of creating or understanding stories, as well as the central role that narratives play in the creation of new interpretative models of reality. The narrative dimension was not understood by the research group as a simple means of expression including pre-established metaphorical schemes, but rather as a cognitive tool, able to guide the conceptual understanding of metaphors, to extend their inferences and encourage the independent production of new metaphors and associations.

In addition to the narrative aspect, the research team paid particular attention to the communicative context in which the metaphorical narratives would be presented to the students in the experimental classes. In order to ensure communicative effectiveness, the interaction between the expert teacher

[19] For a more in-depth analysis, see Herman 2010. A recent experience of science education designed on the basis of exploiting the cognitive potential of narratives and the heuristic potential of metaphors is described in Fuchs et al. 2018.

who presented the stories, and the students of the experimental classes was designed by alternating between the exposition of the narrative text and the active participation of the students: they were asked to comment and propose interpretative analyses of the content of the stories and the metaphorical devices contained therein. The exposition of the scientific contents was also interspersed with questions addressed to the students and aimed at ensuring their active participation in the control classes. This interactive mode of teaching was intended to encourage the autonomous generation of metaphors from the suggested analogies/metaphors, as an exercise in familiarization with the figures of language and the development of autonomous cognitive skills.

Finally, workshops were designed to allow all the students involved to actively elaborate the contents through expressive languages. For this design, it was important to collaborate with Professor Ashley Gess[20], who was a source of important suggestions for the development of workshop activities, designed on the basis of the elements that structure the STEAM [21]education.

3. The empirical research

The research project involved six classes belonging to the Istituto Comprensivo "Leonardo Da Vinci" of Reggio Emilia. The teachers of each class involved participated in the planning phase. Students from six parallel classes took part in the activities: two from the fourth year of primary school, two from the fifth year of primary school and two from the first year of secondary school. In this paper, only the research in the lower secondary school is presented; the activities were carried out more completely and continuously for unrelated reasons.

The researchers provided a pre-test to the classes, in order to verify the starting conditions with respect to prior scientific knowledge and level of comprehension of a text and consequent comparability of the experimental data. The administration of the pre-test[22] was preceded by the presentation of the themes of the project and of the researchers directly involved: these activities took place during the first of the five meetings of the empirical research. The second and third meetings in the experimental classes were dedicated to the reading and discussion of the narratives developed by the research group[23]. The control classes, on the other hand, were offered a traditional didactic text, which did not meet narrative or metaphorical expository criteria. [24]

[20] Lecturer in STEAM education at Augusta University (Georgia, USA).

[21] Science, Technology, Engineering, Art and Mathematics. Here it is understood as a broad set of educational and design strategies aimed at promoting dialogue between scientific disciplines and the related intertwining of competencies from a global developmental perspective (De la Garza and Travis 2019)

[22] The pre-test consisted of two tests: the first aimed at verifying previous knowledge about the structure of the cell, consisting of four multiple-choice questions, followed by an open question. The second test, aimed at verifying the ability to understand a text, consisted of a short narrative text and five multiple-choice questions. Students with special educational needs or language difficulties were given a simplified version of the text.

[23] In both cases, the interaction between the experienced teacher and the students was based on the reading of texts of a similar length, without images, which were video projected in the classrooms through the use of the interactive whiteboard.

[24] In both cases, the content was presented by an experienced teacher, hired specifically for the experiment, and the interaction was documented by a researcher through the use of a microphone, a digital video camera and an observation table.

At the end of the third meeting, the researchers administered the post-test in both the experimental and control classes to check the knowledge and skills acquired. [25]

In the fourth meeting, a workshop was conducted based on the STEAM Education paradigm, dedicated to a further elaboration of the contents presented during the previous meetings through the interaction of students in small groups and the use of expressive languages. [26]

In the fifth meeting, a follow-up test was administered online[27], aimed at collecting useful data to verify the differences between the students of the experimental class and the control class with respect to the consolidation of learning and its permanence in the medium term. A second follow up[28] was carried out five months after the fifth meeting to collect further data on the consolidation of learning in the long term.

For the evaluation of the answers to the open questions, the group decided to consider as wrong the answers which had at least one of the following characteristics: presence of serious errors, number of errors exceeding the number of correct elements, very generic answer, very incomplete answer.[29] The rationale for this choice was twofold: to shift the comparison between the answers of the two classes to a qualitative level, and not to exclude a priori some "imperfect" answers from the qualitative analysis. In the overall comparison between the results of the two classes, the percentage of decidedly wrong answers and of lack of answers was considered significant quantitative data for the evaluation of the methods' efficacy.

4. The test results[30]

4.1 Comparing the answers

[25] The post-test included one open-ended question and four multiple-choice questions related to the structure of the cell, all followed by a request to add a comment. The questions concerned the cell in general and some of its components: ribosomes, the cell membrane, enzymes, and mitochondria.

[26] In both the experimental and control class, the workshop involved dividing the students into small groups, each consisting of four to five members. Once divided into groups, the students were provided with graphic-artistic materials. The delivery of the materials was followed by the illustration of the workshop proposal, consisting of the question: "How would you represent the cell to a friend of yours who doesn't know it?". The students were then invited to use the available materials to visually represent the cell, in order to creatively describe its structure.

[27] Due to restrictions on in-person activities due to the ongoing pandemic, the test was administered by sharing a link that allowed students to access an online form rather than on paper.

[28] This second follow up was also carried out to have more homogeneity with the first activities, as the first follow up, due to restrictions resulting from the ongoing pandemic, had been carried out remotely. The follow-up consisted of a single open-ended question on the cell.

[29] The evaluation rubric used included the following parameters: completeness, originality, relevance of the answer (selection of information), conceptual coherence (organization of knowledge), appropriateness of vocabulary (expressive mastery). Answers containing inaccuracies and errors were included only if they did not have a greater weight than the correct contents of the text. Following the same criterion, generic answers and repetitions of closed answers were included in correct answers.

[30] For a more in-depth analysis of the research results, cf. Giuliani and Manera 2021 (forthcoming).

Firstly, the pre-tests administered in the two classes confirmed the validity of the comparison. The students showed a fairly similar level of initial knowledge.[31] This initial equivalence makes the advantage of the experimental class particularly significant in the comparison between pre-test and post-test: comparing the results obtained in the closed questions ~~in the post-test~~ in the two classes, the improvement ~~in the post test~~ is found to be ~~clearly~~ higher in the experimental class (see Figure 1 below).

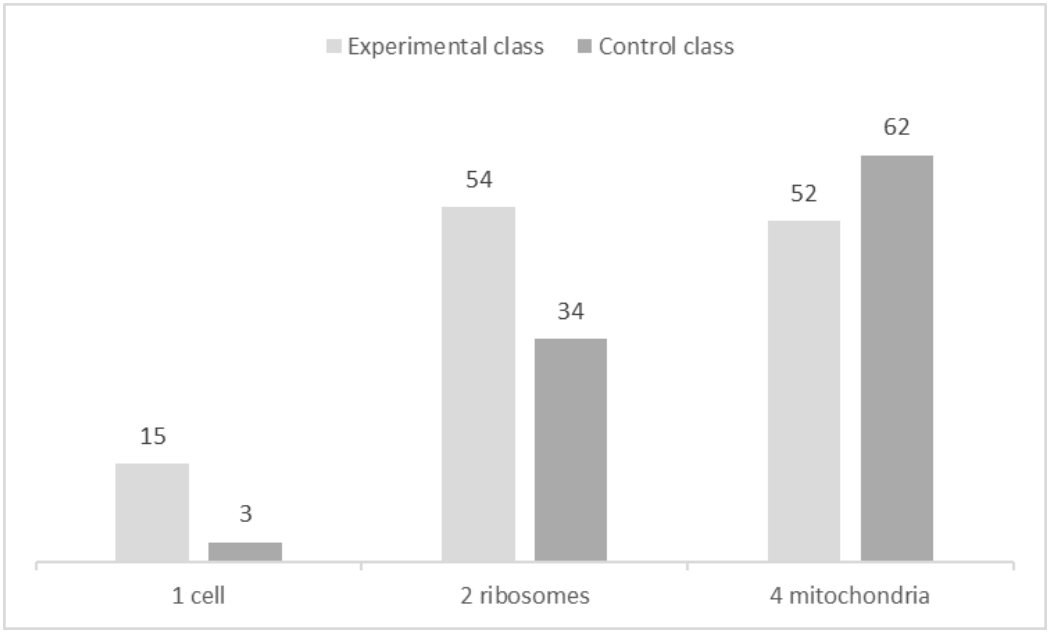

Figure 1 - Percentage increase in correct answers to close-ended questions from pre-test to post-test within each class

The question about mitochondria seems to be a partial exception. However, the difference is reduced if we consider that the number of answers to the open-ended question on mitochondria is higher in the experimental class. If we look ~~instead~~ at the overall graph of correct open-ended answers on the post-test (see Figure 2 below), the experimental class generally has an advantage with regards of the answers to the questions about the different components of the cell.[32] This advantage concerns both the number of correct answers and the quality of the answers in terms of completeness, originality and absence of misconceptions.

[31] The percentage of correct answers to the closed questions out of the total number of participating students is in fact on average similar in the two classes, with deviations that do not exceed 15%. In particular, as far as the question on the ribosome is concerned, the answers of the pre-test indicate a completely equivalent and very low level of previous knowledge in both classes. An exception is the question concerning the cell membrane, for which the percentage of correct answers is decidedly higher in the experimental class.

[32] The gap is rather sharp in particular, both, as we said, in the question on the ribosome (n. 2) and in the one on mitochondria (n .4).

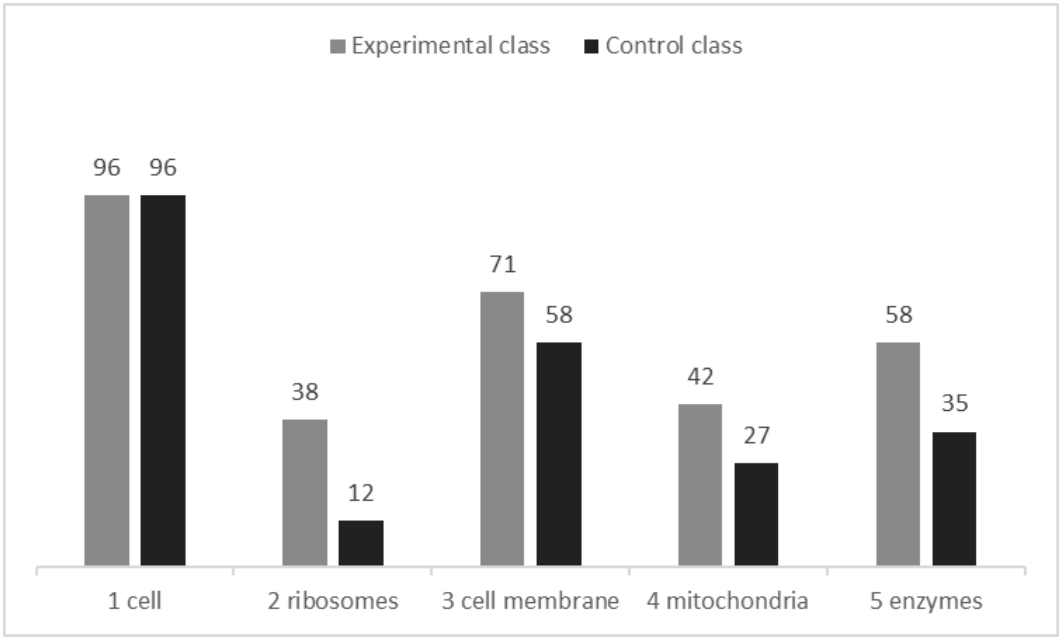

Figure 2. Percentage of correct answers to open-ended questions on the post-test

If we compare the answers to the same questions in the two classes, the general advantage of the experimental class is better articulated. With regard, for example, to the question on ribosomes, in the control class, not only do we have a markedly lower percentage of correct answers over the number of students (12% instead of 38%), but also the use of repetition: the correct answers repeat the correct closed answer to the corresponding multiple-choice question with minimal changes. This difference indicates a possible gap in content processing and reinforces the significance of the quantitative differences in the responses to this question.

Similarly, in the answers on mitochondria (n. 4) of the control class, a higher number of answers contains incorrect and irrelevant information, as well as a higher number of repetitions. We obtain therefore an indication of a lower diffusion and awareness of learning[33].

Regarding the responses on enzymes, absence of misconceptions in the incorrect answers[34] emerges in both the experimental and the control class. This finding, while not demonstrating an advantage of either class, is nevertheless important: it indicates that the different learning resources used in the two classes were in any case adequate and not misleading with respect to the content to be learned, and therefore comparable in terms of effectiveness.

In answer to question 6 ("*How would you explain the cell to a classmate who does not know it?*") the weak advantage of the control class with respect to the number of correct answers is compensated for by the better quality of answers of the experimental class. They show a more pronounced development of processing also compared to the answers to open question n. 1 ("*Now try to describe the cell*"): not only does a communicative and non-standardized expressive mode emerge, but new associations and new conceptual implications can be identified. The answers of the control class have

[33] With respect to the quality of the answers, in this case in the experimental class a scarce originality is attested and, in many cases, the function of the mitochondrion is confused with that of the APT. This, however, does not diminish the significance of the difference between the results of the two classes; on the contrary, it can be interpreted as an index of a difficulty of the subject that reinforces the weight of the better result obtained in the experimental class.

[34] Only one is really wrong while the other two are just too general.

a more formulaic aspect and are all rather short and standardized (in particular, the formula "The cell is born, grows, reproduces and dies" is recurrent).

4.2 The use and role of metaphors

Regarding the use of metaphors, the analysis of the contents of the answers gives an indication of a link between the better articulation, completeness, and originality of the answers of the experimental class and the use of metaphors. In the experimental class, we record, first of all, the quantitative data: more than 40% of the students use metaphors in their answers (we have a lower percentage only in the question on the cell membrane). While the predominantly metaphorical quality of the answers may be the consequence and simple reflection of the type of approach used in the lessons, it is more significant that almost all the answers that contain metaphors are correct. Moreover, the repetition of the metaphors in the story does not appear as a mechanical reflection of what was heard: metaphors tend to be open to autonomous elaborations and allow for new implications[35].

The analysis of the content of the answers offers us further elements of observation regarding the type of metaphorical imagery that was involved in learning. As regards the first open question, which asked students to describe the cell, the prevailing metaphor used in the experimental class is that of the *world*, declined and elaborated as a sort of analogical model.[36] Looking at the linguistic aspects, we observe that the most recurrent term in the story was "world", while students in the post-test prefer the term "planet". This could depend on the fact that "planet" is a term used by the children who were protagonists of the story, but also on the fact that the suggested correspondences between cell and "world" recalled to the children geographical knowledge learned in other lessons. Metaphor seems to have functioned as an attractor of prior knowledge, encouraging connections and elaboration for the benefit of complexity. On the other hand, the term "world" stimulated autonomous connections: the cell-world associations, in fact, went beyond the geographical-natural aspects suggested by the context of the story, orienting rather on world as an inhabited or populated place.

In the answers to question n. 6 ("*How would you explain the cell to a fellow student who doesn't know it?*") the quality of the answers, including new implications and associations, corresponds to a further elaboration of the metaphors: for example, we have a mixture between planet and "city", presented as a context of mixture between natural and human elements[37]. In another answer, the world-metaphor promotes the recovery of the idea of an interdependence of things ("where each thing

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[35] For example, in the description of the membrane, the metaphors of "skin" and "frontier", both present in the story and elaborated in the lessons and in the workshop, let the concepts of "cover", "protection", "filter" emerge. In addition, the metaphors act as a vehicle for further associations: the connection between the image of the skin, of the frontier and the idea of protection allows the image of the "protective shield" to emerge and the analogy with the earth's crust, further articulation of the "model" of the planet. In the answers to the question about enzymes, 82% of the answers have metaphorical elements: the metaphors of specialized work, care, and repair are taken from history. Also here, however, we find significant variations: repair is more visible than in the story, and new linguistic expressions emerge (the "handyman" enzyme, the "cure", the "repair" of wounds) that can be the result of an individual elaboration or of the interaction occurred in the groups.

[36] We speak of a world "where the fundamental units for living are the sea (cytoplasm), the forest (cytoskeleton) and the land (the organelles)"; elsewhere, DNA is "surrounded by a sea with land where there are trees".

[37] Typical elements of cities are mentioned along with "rivers," "lakes," and "cars" (used for "automobiles"), albeit with a confusion between the terms microtubule/mitochondria.

depends on another"): in the story there is indeed talk of help, collaboration, but the connection of this concept with being a "world" is a new connection compared to those established.[38]

Overall, the characteristics of the responses seem to indicate that this question, which contextualizes the request for explanation in a peer communication, also stimulated, along with the activation of personal and metaphorical imagery, inferences and analogical reasoning and was revealed to be useful in organizing and connecting information.

The supposed correlation, in the experimental class, between the use of metaphors and a better quality of the answers based on the parameters considered is also supported by the comparison with the control class. On the whole, as we have said, in the control class we find a greater tendency towards repetition, a poor reworking of terminology and very little use of associations and comparisons. This result becomes even more significant in the answers to question 6. The invitation to simulate a conversation among peers seems to have stimulated a personalization and a greater "responsibility" in the answers, which are longer and richer in information, but the adequate resources to respond seems to be lacking: original language and conceptual elaboration are scarce, and the writing style is imitative with respect to the proposed didactic text (we already mentioned the frequent repetition of the formula "it is born, it grows, it reproduces, it dies, it reacts to stimuli"). However, it is worth noting that the few metaphors proposed seem to respond to those unfulfilled needs of communicative expression and elaboration[39]. In particular, among the answers we find one interesting and spontaneous "metaphorical exercise": the idea of the floating particles brings to mind the image of the little boats "which give food to the cell", as if they brought supplies; to this is added the idea of the membrane as a "cloth" which wraps the cell, as if it were a "cradle". These are potentially evocative and effective connections which do not, however, seem to find an anchorage, a reference, in order to be articulated and developed. The rooting and relaunching of implication in the case of the lessons of the experimental class is offered by the narration; in the absence of this resource, the potential of the metaphor seems to remain unfulfilled.

4.3 The follow up tests: metaphors and long-lasting learning

The two follow-up tests that were conducted in the following months offered consistent and integrative indications with respect to what was observed in the post-test. In the first follow-up, contingent variables do not allow a direct comparison with the previous results,[40] but the variables

[38] Along the same line, we can also mention the idea of the "living planet", which is associated with that of the planet and which in turn recalls the metaphorical idea, present in history, that even small things can be "great and indispensable". We note, linked to this concept, the reference to the cell as "a part of us" but capable of its own self-sustenance, therefore autonomous: this idea was proposed by the teacher in class following the workshop, but it is likely that the metaphors of the story and the comparison during the lessons in the project constituted the premise for accepting this concept.

[39] For example, a student from the control class, in order to explain his response on the cell membrane, uses the comparison with a familiar object (the cover of the exercise book) that responds to the idea of protection. The concept of the cell as a "living" entity seems to have stimulated the imagination by evoking the association with the human being and starting a search for correspondences: the metaphorical potential of the cell "similar to man" is therefore articulated in suggestive implications whereby the cell "breathes the air we breathe", "the cell is us".

[40] Firstly, we have a change in modality: the follow-up was carried out remotely and online, thus leaving the students with the potential access to further information. Secondly, there was an integration of the experiences

(equal and randomized for the two classes) do not invalidate the comparison between the results of the two follow-ups.

First, there is a greater number of answers to the question on enzymes in the experimental class.[41] Another interesting element, if we compare the answers according to the other evaluation parameters (completeness, elaboration, originality), is that again, as for the post-test, the answers to the question on the ribosome in the control class are more uniform and repetitive.[42] This greater uniformity and repetitiveness of answers may indicate, regardless of the correctness of the answers and the way they were found, a lesser elaboration of information.

As regards the use of metaphors in the online follow-test in the experimental class, it is worth noticing that the students, at that time, had carried out further activities and had access to additional information: it follows that here the eventual use of the metaphor becomes a conscious choice and then acquires additional value. The general tendency is a decrease in the use of metaphors with respect to the post-test[43]: metaphors are little used in the follow-up, especially in the questions on the single components of the cell. Moreover, in general, compared to the post-test, descriptive aspects emerge compared to the functional ones: apparently, in the medium-term memory, other information prevailed over the metaphors of the story[44]. But it should also be noted that instead metaphors are chosen, again, to answer question n. 6, which is individuated as an "authentic task"[45] also because the question, unlike the post-test question, asks you to tell and not to explain the cell: here the language used recalls the concepts of *world, life, work, machine*, all brought into play in the story, which also seem to meet the direct experience of the students.[46] Moreover, further metaphors emerge in addition to those suggested by the story. For example, the cell itself is presented as a small living being, "*creating our body parts and making them work through helpers*". This is a metaphor loaded with potential implications and correspondences: the human body appears almost as a machine (that "must work") and the cell as a living-worker. The original metaphor inverts the one of the cell as a "*perfect mechanism. Where everything is in its place and everything works perfectly and if something goes wrong it can be easily replaced*".

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and knowledge acquired by continuing with the workshop and further classroom lessons after those carried out within the project. Moreover, as regards the comparison between the two questions dedicated to the cell, 1b and 6, we have to consider that in no. 6 we asked to "tell" the cell, thus favoring the adoption of a different expositive register.

[41] In the control class the percentage of students who decide to answer this question is much lower (59% in the control class, 85% in the experimental).

[42] They often have exactly the same incipit ("ribosomes are round in shape").

[43] For example, the association between the shape of the mitochondrion and that of the bean prevails throughout, while the reference to ships, to the power station, to batteries is absent; only the comparison with the peanut in the story or - confusing the mitochondrion with the ribosome - to the ball of yarn remains, with only one reference to the "workers" inside the mitochondria.

[44] But it may also be assumed that the description requested is now associated with visual aspects, perhaps because of the visualisation exercise carried out in the workshop.

[45] It thus brings into play a competence, since the restitution of learning must be used for a further operation, aimed at a communicative and sharing purpose.

[46] The metaphor of the "planet" returns ("it is very small but it is like a planet", "I will tell it like a small world where everything happens like on earth but in a different and smaller way"), articulated in various correspondences and implications, again as an analogical model ("it is like a planet, which instead of the mantle has a gelatinous substance called cytoplasm, and the nucleus is not made of lava but has DNA strands, the crust is called cell membrane and inside the cytoplasm there are many organelles that together make the cell survive").

The indications emerging from the results of the experimental class are reinforced by the differences we find in the control class. Here, the answers to question n. 6 of the follow-up, despite the potential access to new information, tend to repeat the list of information already proposed to answer the descriptive question (1) and again offer a very standardized and less communicative language and way of expressing themselves (e.g., repetitive incipit with "The cell is the smallest living unit") and a list-like writing style. It is also important to note that, as in the post-test, the answers with metaphors are also those where expression is more personalized and also where additional or more precise concepts appear [47].

The aim of the second follow-up test, administered six months after the previous meeting, was to detect indications on the memorization of contents in the long term. To this end, the classes were asked a single open-ended question: "How would you ~~explain~~ tell the cell to a classmate who does not know about it?" [48].

The results of the experimental class were positive overall.[49] Just under half of the students formulated fairly complete answers, linking a plurality of information. Looking at the specific content of the answers, it is significant that the information includes the function of ribosomes, which had previously been an element of difficulty. Regarding inclusiveness, it is significant that students with Special Educational Needs and Specific Learning Difficulties (Italian BES and DSA) not only manage to give answers that are not wrong, but sometimes overcome the minimum objective of restitution.

With respect to the use of metaphors, students who had already used the metaphors of the story, recover them in this context in a way appropriate to the concepts involved[50]. Moreover, metaphors that were not present in the previous tests emerge in many answers (41%).[51] It may be assumed that contents related to metaphors in the story have held up well in the long run, and they have encouraged the production of new metaphorical associations and their use as explanatory tools.

The comparison with the October follow-up of the control class supports that interpretation of the results of the experimental class. The answers are more fragmented than those of the experimental class: we have a limited amount of information[52], little in-depth content, poorly structured discourses, unconnected elements. More than half of the answers are very poor in content, compared to only 14% of the experimental class, and only 2 or 3 answers can be really considered complete. The answers also have a different expositional quality: the style is less communicative, with formulaic aspects,

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[47] In one case, a metaphor clarifies the command function of the nucleus, which in the other answers is always expressed rather generically; in the other case, an attempt is added to refer to the shape of plant cells with the image of "branches growing out of the corners" of the cell.

[48] It was considered that time spent increases the variables, but also that this variability affects both groups equally randomly. Unlike the first follow-up, moreover, in this case the variable of the distance and online mode was eliminated, given that the activity was carried out in the presence, without therefore the possibility of access to external information.

[49] Approximately 80% of the students give answers in which the correct information prevails and can be considered correct according to the evaluation rubric adopted. 59% of the answers contain no errors or only minor errors. Only 14% of the answers are very incomplete and/or mostly incorrect.

[50] E.g., the nucleus as heart or brain, the cell as planet or small world, the cell as brick.

[51] The country (rather than the planet); the nucleus as a mountain; the substances that enter as "allies" of the cell, developing the metaphor of defense and conflict; the "reading" of RNA.

[52] We find the nucleus and the cellular membrane, but we never find mention of the mitochondria and the ribosomes, which do not appear therefore as an element of difficulty. Among the functional aspects, the defense of the DNA by the nucleus, its command role and the protection role of the cellular membrane are mentioned, but only 5/21 answers contain both this information.

much uncertainty, and little activation of the imagination (only two answers propose metaphors and associations). In terms of errors, we find widespread and established conceptual confusion regarding the relationship between body and cell, which emerges as a kind of organism contained within the body and not a constituent of it.[53]

Another interesting aspect emerges: many students (8/21, 38%) feel the need to integrate what they write with a drawing of the cell, taking up what had been done in the workshop. Students seem here to consciously choose the mode of visualization they experienced in the workshop. It might be assumed that drawing and visualization fulfil a need for communication and explanation, which in the experimental class is carried out mainly through metaphor.

The general indication that can be drawn from these results is that images and metaphors were spontaneously used by students as a support for sharing and processing of learning but in the absence of a targeted listening and a structured guidance, for example through the narrative, their potentialities risk remaining unexpressed.

5. Observations on the activities and feedback from the research group

After the conclusion of the activities in the classes and the analysis of the test results, a webinar was organized to give back the results of the research. The seminar was an opportunity to integrate the analysis of the test data with the comments of the expert teacher who conducted the experiments and those of the teachers of the classes involved.[54]

The feedback on the lessons and workshops helped to define the quality and role of interaction. The constant and discreet interaction during the lessons was said to be constitutive for the understanding and further elaboration of metaphors in the classes. It was noticed that the verbal expression during the interaction was in many cases richer than what the students were able to report in their written answers[55].

Concerning the interaction in the workshops, it was reported that the works were the result of choices shared by the whole group, which proved to be adequate and consistent with the contents to be represented.[56] The use of non-verbal resources showed a good understanding of the contents and metaphors proposed, in line with what emerged from many open-ended answers on the tests. In the control class, students with learning difficulties (BES and DSA) also participated effectively, as an indication of the inclusive value of the activity. It is significant that, in this case, even in the face of interaction and freedom of delivery, the work was very precise but constrained to formal and already structured aspects.

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[53] A significant number of responses (8/21, 38%), in line with this ambiguity, state that the cell is a microorganism or a unicellular organism.

[54] The seminar was held online on December 9, 2020 and was attended by the members of the research group and the teachers of the middle schools. The lack of other figures taking part in the research was due to the difficulties still related to the management of the Covid19 emergency.

[55] For example, with regard to mitochondria, a further metaphor emerged “they are like bakers, taking flour and making bread to give to people”; with regard to the communication among enzymes, the “word of mouth” metaphor, also, one pupil noted that with word of mouth, information changes, wondering about the consequence.

[56] For example, the cell membrane represented with paper, which functions as a filter to get in and out, a sphere that is gradually discarded to find nucleus, the threads of the ball used for DNA strands.

In commenting on the results collected by the research group, the teachers who took part in the seminar declared that, on the basis of their previous professional experience as well, the narrative-metaphorical modality in the educative relationship is inclusive in favoring the educative relationship and better supporting attentional capacity. From their point of view, metaphor offers students a key to access their own experience and at the same time brings the teacher's experience into play, supporting sharing and interaction between their respective experiences. In addition to facilitating comprehension, the experimented modality proved to be a support for the relationship, with the teacher and among the students.

Finally, the teachers pointed out that metaphors, together with images, are also part of the contents to which children are exposed in textbooks and which they use spontaneously. This spontaneous generation of metaphors occurred, in fact, also in the control class, as we have already seen attested by some of the test answers. The proposal of metaphors in the experimental class was therefore an intervention that enhanced a tendency that spontaneously belongs to the students' way of knowing and was not perceived as the introduction and imposition of an external element: metaphors and narration were rather seen as an encouragement and support for the effective use of a resource that, albeit in a limited way, is already used by the students. The research team agreed instead that the absence of structured metaphorical associations and narration in the control class meant that there was a lack of a means of guiding and structuring the implications of the metaphors that nevertheless tended to emerge from students' discourse.

With respect to one of the possible criticalities of the narrative and metaphorical modality, that is, the risk of taking attention away from technical-scientific language, the research group highlighted that in the written answers the students used different linguistic registers. A further indication with respect to the ability of metaphor to support a correct use of scientific language also came from the October follow-up, which gave clear indications about the difference in the quantity of concepts memorized: the group observed that with the bridge of metaphor, with the same intervening variables, in the experimental classes, many concepts crossed a considerable temporal distance and variety and complexity were preserved.

The research group also noted that narration, metaphors and visualization, especially when interconnected, can highlight misunderstandings better than literal language, especially in the context of formative assessment.

6. Conclusions

The results of the research, including the results of the analysis of test responses and the results of the comparison in the research group, have provided indications to support the thesis that metaphors, if placed in a narrative structure that facilitates understanding and guides its implications, can favor:

- the organization of contents;
- the understanding of complex concepts
- an informed use of scientific language;
- a long-term storage of learning content;
- the original elaboration of learning content, similar to what happens in interaction and workshop activities;

In addition, an analytical focus on the use of metaphors and the enhancement of their production encourages:

- the recognition of misconceptions;
- continuity with an attitude already present in the students and with their ways of learning;
- an inclusive aptitude for participation, communicative exposition and original elaboration of learning content.

The results of the research have also strengthened the conviction that it is necessary to adopt aesthetic categories, in addition to specifically cognitive ones, in order to account for some specific aspects of metaphor: for example, an aesthetic approach is necessary to define the ability of metaphor to "make one feel" and "make one see" what it intends to say; the ability to "make present", to put before one's eyes, and not only to refer to something (Ricoeur 1977, Franzini 2020, Messori 2020, Dahlin 2001). The creative and cognitive power of metaphor in this sense is not only reflected in the possibility of making something known. In "strong" metaphors, the result of the interaction overcomes the analytical aspects of the projection. The metaphor that takes on this *poietic* value makes something *happen*, rather than "referring to something". It establishes a virtuality in which the starting elements are no longer the same, something that has its own "sense" that is different from both, even though it finds its "reason" in the interaction.

What conclusions can we draw provisionally for the educational and didactic field? The importance of educating with metaphors, of stimulating the exercise of their comprehension as a resource for knowledge is enhanced; at the same time, it becomes fundamental to educate *to the* metaphor, to exercise the imagination that presides over its construction, to accompany and relaunch the associations of the children themselves, cultivating competence in listening to themselves as well as to others. Both these aspects are fundamental if, in learning processes, *creativity* becomes another way of defining *knowledge*: if "to know" means to welcome and respect an "otherness" that is *renewed* in that relationship, education to metaphor becomes this form of education to give oneself new possibilities together and to generate together what to understand and take care of.[57]

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[57] Cf. also Giuliani 2021 (forthcoming).

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