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# Hierarchical Organization in Concept Maps as a path to explain the Elaboration of Knowledge in the History of Science

**Paulo Victor Santos Souza[1,2], Marta Máximo-Pereira[3,4], Ariane Baffa Lourenço[5]**

[1]Department of Physics, Instituto Federal do Rio de Janeiro-campus Volta Redonda, Brazil, [2]Laboratório de Pesquisa em Ensino e Divulgação da Ciência (LAPED)-Universidade Federal Fluminense, Rio de Janeiro, Brazil, [3]Centro Federal de Educação Tecnológica Celso Suckow da Fonseca - campus Nova Iguaçu, Brazil, [4]Laboratório de Pesquisa em Ensino de Ciências (LAPEC), Brazil, [5]Centro de Síntese USP Cidades Globais-Instituto de Estudos Avançados - Polo São Carlos, Brazil

***Corresponding Author:** paulo.victor@ifrj.edu.br

## ABSTRACT

An alternative to insert history of science (HS) in teacher formation programs is the use of concept maps (CM), which may be very useful to represent the historical elaboration dimension of science concepts, laws, and principles. This paper presents the results of a study that identifies the conceptions of pre-service physics teachers about the relationships between CM hierarchical organization and knowledge elaboration in HS. In the first stage of the research, the content analysis methodology was used to analyze and categorize the students' answers to questions concerning the relationships between CM hierarchical organization and HS. In the second stage, the answers of a different group of pre-service teachers were analyzed concerning the level of agreement with the categories previously elaborated. The students associated CM hierarchical organization with knowledge improvement, elucidation of the importance level of the concepts, and the relationships between more general and more specific contents. We point out that the use of CM in HS subjects may contribute to the pre-service teachers associating HS concepts not in a chronological way, but in hierarchical order, from the most general to the most specific ones.

**KEY WORDS:** Concept map; hierarchical organization; history of science; teacher formation

## INTRODUCTION

The history of science (HS) has been understood for around 30 years by research in science teaching as an extremely relevant aspect to be approached in science classes (Matthews, 1992) and, consequently, to the formation of teachers of science subjects. According to Matthews (1997), there are at least two arguments for the importance of science teachers knowing the history and philosophy of science. One is the pedagogical argument, which refers to making science understandable for the student, characterizing it as systematized human knowledge and making it possible to develop criticality and logical thinking. The other one is the professional formation of teachers, who must comprehend the subject they are teaching and the ways humankind uses to elaborate that knowledge to be presented to the student.

For Klopfer and Aikenhead (2022), approaching HS with students allows learning from a humanistic perspective. From this perspective, besides the scientific knowledge itself, the nature of science and the interactions between science/scientists and society must also be considered in learning. However, the use of HS, to teach science and about science, as well as to promote the professional development of teachers, concerning knowledge as the knowledge that teaches, was constituted historically, and it is still a great challenge for in-service and pre-service teachers (Matthews, 1994; Höttecke and Silva, 2011).

A possibility to represent a scheme of knowledge elaboration in the HS is the use of a concept map (CM), as initially proposed by Nersessian (1989) and Thadgard (1992). The authors aforementioned used CM to illustrate the process of concept change in scientific revolutions. More recently, Maximo-Pereira et al. (2021) identified the proximity between the concept mapping technique and the elaboration of science knowledge in HS, pointing out that the CM may be used to represent the historical elaboration dynamic of concepts, laws, and science principles.

Considering the elements constituting a CM-focal question, concepts, propositions, two-dimensional structure, crosslinks, and hierarchical organization (Novak and Cañas, 2006), in its relation to HS, this manuscript shall dedicate to the study of how pre-service teachers consider the relation between hierarchical organization and the construction of knowledge in HS, to answer to the following question: what are the conceptions of pre-service teachers concerning the relations between the hierarchical organization of CM and the elaboration of knowledge in HS?

The hierarchical organization was chosen to be investigated because it makes possible to identify how the subject relates to the concepts when arranging, in a hierarchical way, the most general/inclusive ones at the top of CM and the most specific, subsequently. The hierarchical organization allows us to observe which relations the students consider important for each concept, as well as his creativity in presenting such concepts (Cañas et al., 2015; Marques and Coelho, 2020). In the investigation of Demirci and Memis (2021), the pre-service teachers investigated pointed out that the hierarchical investigation provided "a better comprehensibility level, and it helped them see the concepts clearly and the subject as a whole" (p. 268).

This way, it is an element of CM that allows us to present hierarchically how more general knowledge elaborated by science is specified from agreements or disagreements between different comprehensions developed by humankind along HS (Maximo-Pereira et al., 2021). This understanding of the role of hierarchical organization in a CM on HS is compatible with a view of science as a human construction, in permanent change, being developed based on consensus and dissent within the scientific community.

## Theoretical Framework

CM is a graphical tool for organizing and representing knowledge in different knowledge domains (Cañas et al., 2015). "They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts indicated by a connecting line linking two concepts" (Novak and Cañas 2008, p. 1). To elaborate a good CM, it is important to consider the presented criteria in sequence, as well as be aware of the quality of the concepts and their graphical structure (Cañas et al., 2015).

a. A context for the concept map should be defined, commonly with a stated explicit "focus question."
b. Concept labels in maps should be only one or a few words labeling a specific concept.
c. Linking lines should be labeled with one or few words, and not contain concept labels important to the map's conceptual content. They specify the proposition or principle formed by the concepts and linking words.
d. Cmaps should have a hierarchical organization, with the most general, most inclusive concepts at the top, and progressive more specific, less inclusive concepts at lower levels.
e. In general, no more than three or four subconcepts should be linked below any given concept.
f. Crosslinks should specify significant interrelationships between two concepts in different subdomains of knowledge shown in the map. These are best added when the map is nearing completion.
g. Concept labels should not appear more than once in a given map. (Cañas et al., 2015, p. 8)

The CM has been used for some decades for a variety of applications and, in particular, as a tool to help the teaching and learning process in different areas of knowledge (Demirci and Memiş, 2021; Cañas et al., 2015; Roth and Roychoudhury, 1994). Specifically in initial teacher training courses, in the research held by Demirci and Memiş (2021), pre-service teachers report "they had to know the subject related to the concept map very well in order to create concept maps (CM) more easily, otherwise it might be difficult to go through the concept map creation process" (Demircil and Memiş, 2021, p. 264).

Concerning the investigation on the use of CM in teaching HS at the higher education level, we highlight the work of Maximo-Pereira et al. (2021), who have recently proposed the existence of corresponding characteristics between the concept mapping technique and the elaboration of scientific knowledge in HS. The authors support that the process of concept mapping and of construction of scientific knowledge present characteristics that may be interpreted as corresponding and that allow the establishment of theoretical relations between them.

Such closeness or correspondences were exemplified by the construction and analysis of a CM on how historically knowledge was developed in a way to result in the Law of Inertia. As a conclusion, structural aspects of the CMs (propositions, two-dimensional structure, crosslinks, etc.) were related to the provisory feature of scientific knowledge, the nonlinearity of its development, and the influence of the historical and social context in the construction of knowledge, among other aspects compatible with a conception of science

**Table 1: Summary of the relations between concept maps and dynamics of elaboration of scientific knowledge in the history of science**

| Elements/characteristics of the concept map | Relations in the history of science (HS) |
|---|---|
| Focal or theme question | It guides the explanation of the historical dynamic of the knowledge involved in a given episode of HS or in the formulation of a law or scientific concept. |
| Concept | It expresses regularities in events, phenomena, theories, and laws, among other aspects concerning HS. |
| Linking word/sentence | It specifies a relation between concepts in the HS, including allowing the expression of different conceptions along HS. |
| Proposition | It establishes the relations of the phenomena studied, scientific theories, and laws developed along HS. |
| Hierarchical organization of concepts | It allows presenting hierarchically how more general problems of HS have been specified in the function of convergence/divergence between views of the world over time. |
| Crosslink | It allows presenting complex inter-relations/relations between conceptions present in different moments of HS. |
| Two-dimensional structure | It allows presenting elaboration of knowledge in the HS in a non-linear way, sometimes simultaneous or dispersed in time and space and involving several actors, in a process of comings and goings in its construction. |

Source: Maximo-Pereira et al. (2021, p. 12)

**Table 2: Methodology of data collection used in the investigation**

| | |
|---|---|
| Subjects of the research | Pre-service physics teachers distance mode |
| | Subject History of Physics I (HF I) |
| | Subject History of Physics II (HF II) |
| Stage I | 1st semester of 2021 |
| | 15 pre-service teachers enrolled in HFI |
| | Dissertation questionnaire about the use of CM in the elaboration of HS knowledge |
| | Content analysis: creation of categories for the answers in the dissertation questionnaire. |
| Stage 2 | 1st semester of 2022 |
| | 28 pre-service teachers enrolled in HF |
| | Validation of categories by Likert scale questionnaire |

Source: The authors.

as a human venture. Table 1 summarizes such correspondences.

As previously mentioned, in this work, we focused our attention to one of those aspects, namely, the hierarchical organization of the concepts. Among the reasons for this choice, it is the fact that "Novak and Gowin (1984) indicated hierarchy to be the most important structural property of CM because a cognitive structure is organized hierarchically and they discussed CM from a hierarchical point of view" (Demirci and Memiş, 2021, p. 265). The hierarchical organization must be present in every CM and consists of the presentation of the concepts constituting the CM, from the most general to the most including ones, so that they are progressively differentiated in terms of details and specificity (Buchwald and Fox, 2013; Batista and Silva, 2018; Novak and Cañas 2006), to follow the principle of progressive differentiation of the Meaningful Learning Theory (Ausubel et al., 1968). The hierarchical organization of the CM corresponds, in the elaboration of knowledge in HS, to the process of continuous conceptual improvement resulting in the accumulation of convergences and divergences of ideas over time.

Although the elaboration of knowledge happens over time, it is not necessarily linear, once there are concepts that, to be elaborated, need to be based on knowledge produced in different times. Given the nature of scientific making, theories and ideas already abandoned, from time to time, return due to the emergence of new evidence. Ideas are more consolidated in the HS and may be resumed for the solution of new problems and/or serve as the basis for new knowledge. Therefore, in this perspective, HS may present "curvy" or "spiral" trajectories and any attempt to represent them using timelines is, inevitably, restrictive.

This point of view concerning scientific development is shared by Pugliese (2017). According to this author, the epistemology demonstrates that science and, particularly, physics, does not evolve linearly, or cumulatively, as presented in most didactics texts and in so-called traditional classes. On the contrary, it supports that the 'evolution of physics is full of revolutions, crises, changes of paradigms, and fundamental abstractions. In his words, the old paradigm transition to a new one is a conflict of fundamental esthetic alterations instead of a cumulative process. Meanwhile, science is the articulation result and improvement of concepts, techniques, devices, and instruments. The period of the scientific revolution generated structural problems necessary to reconstruct the current theories, methods, and processes in a generalized way and better comprehend the world. Therefore, science has been built over centuries not isolated within laboratories and student's union, but as part of every construction of humanity material reality, sharing views of the world, political contexts, articulations, combinations, and colonizations that allowed the acceptance of certain concepts and theories (paradigms) in a given instant and other theories in other moments (Pugliese, 2017, p. 969).

Moreover, Cornelis (2011) sustains that even though history is hegemonically present in a linear manner in didactic books in classes, these usual presentations do not focus on conceptual bridges and relations between events. According to the author, the comprehension and teaching of history, in particular HS, using timelines, contributed to the promotion of a stereotyped view of science as something absolute and complete. Hence, even though a linear view of history construction has its didactic importance, he proposes that it is complemented by a non-linear approach, that is more sensible to the movements of this construction. This hybrid approach of HS assumes, according to the author, the use of didactic tools as cognitive maps (Cornelis, 2011).

Accordingly, this paper intends to realize how the nonlinearity of the scientific knowledge construction process is present in the view of pre-service physics teachers, in so far as they are requested to identify relations between the hierarchical organization of CM and the elaboration of knowledge in HS.

## METHODOLOGY

The research has a qualitative nature and was developed in two stages, with undergraduate students in physics from the Consortium for Distance Learning in the State of Rio de Janeiro (CEDERJ), in Brazil. CEDERJ represents a pioneering Brazilian initiative, aiming to democratize higher education access through distance learning. Established in 2000, CEDERJ is a collaborative effort involving several public higher education institutions in the State of Rio de Janeiro. This consortium includes prestigious universities such as the State University of Norte Fluminense, the State University of Rio de Janeiro (UERJ), the Federal University of the State of Rio de Janeiro, the Federal UFRJ, the Federal Rural University of Rio de Janeiro (UFRRJ), the Fluminense Federal University (UFF), and the Rio de Janeiro State Technical Education Foundation (FAETEC).

CEDERJ's active centers, known as poles, are strategically located across various municipalities in the State of Rio de Janeiro, ensuring widespread access to higher education. These poles provide necessary infrastructure and support for students

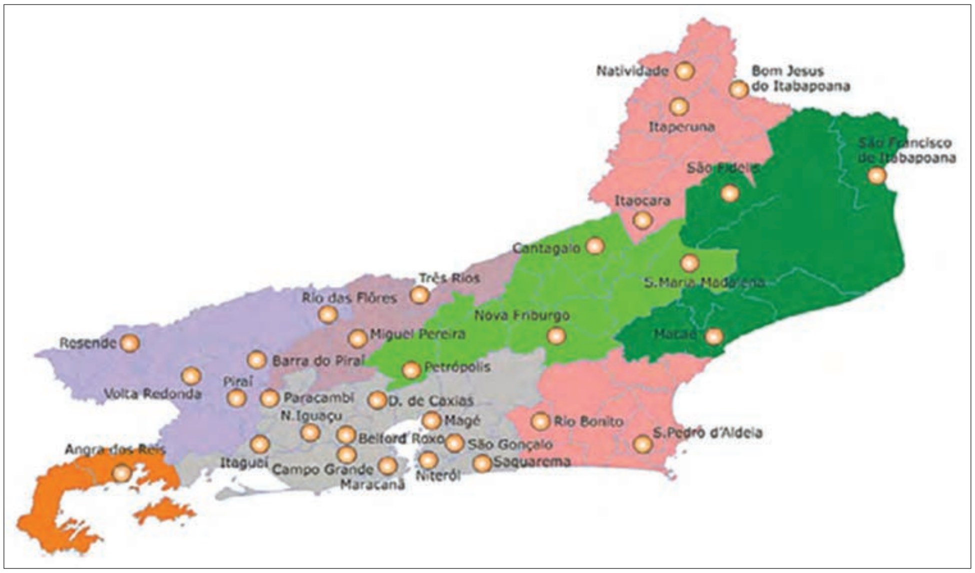


**Figure 1:** Reproduced from Bielschowsky (2017)

enrolled in distance learning courses, facilitating interactions with tutors, access to didactic material, and participation in in-person activities. The geographic distribution of the poles in 2011 is reproduced in Figure 1.

Currently, the state of Rio de Janeiro has 43 Cederj Centers, where students carry out face-to-face activities such as laboratory classes, assessments, and tutoring. In the first semester of 2024, 7,518 vacancies were offered in 17 different undergraduate courses such as administration, public administration accounting, sciences, meteorological engineering, production engineering, biology, physics, geography, history, Portuguese, mathematics, pedagogy, chemical, tourism, technology in computing systems, technology in tourism, and management technology in public security. Consolidated data indicate that CEDERJ currently has 40 thousand students enrolled. The mission of CEDERJ is to offer high-quality public higher education through distance learning, aiming to reach those who might otherwise be excluded from the traditional higher education system due to geographical, economic, or time constraints. Its objective is to provide a comprehensive education that enables professional qualification, promotes human development, and fosters the integration of individuals into the labor market and society.

The physics course has a total workload of 3015 h and is offered by the Federal UFRJ. It has two subjects: History of Physics I (in Portuguese, História da Física, HF I) and History of Physics II (HF II). The subject HF I has a full course load of 60 h and is offered in the 7$^{th}$ semester of the course (which has a total of eight semesters). The subject description goes from the formation of the categories of thinking in physics (since the pre-Socratic) to the rising of the natural philosophy of mechanism and the Newton Laws (Dias and Sapunaru, 2007). The subject HF II, also with a full course load of 60 h, is offered in the 8$^{th}$ semester of the course. The subject description goes from the formation of the mechanic structure of nature to the Thermodynamic Laws (Dias and Sapunaru, 2008). A scheme of data collection methodology adopted in this research is presented in Table 2.

In Stage I, we collected data from fifteen students participating in the subject HF I offered in the 1$^{st}$ semester of 2021 about their understanding of how the hierarchical organization of the CM may cooperate in the elaboration of knowledge of the HS, and we created categories that represent such understanding. In the second stage, we used the categories created in the first one and validated them with twenty-eight students from another class of HFII subject, offered in the 1$^{st}$ semester of 2022. We clarify that the participants of Stages I and II were different, once those stages were held with different classes.

The pre-service teachers investigated in Stage I had their first formal contact with CM during the first assessment of HF I, which was structured as follows: initially, the students were supposed to answer some questions about the mapping technique from the reading of some articles of literature, in special, Aguiar e Correia (2013). Then, they should construct a CM, being oriented by a sequence of suggestions, to facilitate the organization of the concepts and their expression using the CM. The second assessment of the subject did not involve CM, but the contents of HS.

Data collection of Stage I was held in the third and last assessment of HF I. The students were asked to answer the following open question:

"*Between the process of concept mapping and the development of the history of physics some relations are established. We listed below some of the elements of the concept mapping that present corresponding parts in the process of formation of the knowledge in HP: Focal or theme question; Concept; Linking Word; Proposition; Hierarchical organization or concepts; Crosslinks and Two-dimensional structure. Which elements in the process of knowledge formation in HP do the map elements* *correspond to? Justify your answers*."

Although the theoretical framework that bases this question encompasses different aspects of the relation between the technique of concept mapping and the elaboration of scientific knowledge in HS (Maximo-Pereira et al., 2021), in this work, as previously mentioned, we narrow our relation to a single aspect of this relation, hierarchical organization.

To analyze the answers of the pre-service teachers about the relationship between the hierarchical organization of CM and the development of HS, we used the content analysis method (Bardin, 2013). For this, the preparation stages of information were followed employing the reading of the pre-service teachers' answers; creation of analysis units (AU) representing indicators that allowed to understand the relation of hierarchical organization of CM and HS; categorization and grouping of AU; description of each category formed; and interpretation of categories, resorting to references of the literature of the area whenever possible.

The categories aforementioned, whether agreeing or not with the relations between the hierarchical organization of CM and the construction of HS defended by Maximo-Pereira et al. (2021), were presented in Stage II of the research, which occurred in HF II. In the first assessment of the subject, the twenty-eight students of HF II were required to evaluate sentences expressing the categories elaborated in Stage I of the research.

The pre-service teachers were supposed to express themselves about sentences using the Likert scale, with values 1–5, that is, indicating if they totally disagree, partially disagree, neither agree or disagree, partially agree, or totally agree. Complementarily, the students were requested to present justifications for their choices. For the validation of the categories, some of them had their writing with didactical purpose, to fit the assessment model use, without prejudice to the pre-service teachers' understanding.

## RESULTS AND DISCUSSION

In this section, first, we present the categories created in Stage 1. These came from the statements of pre-service teachers about their understanding of how CM may cooperate in the elaboration of knowledge of HS. Next, the validation of the corresponding categories by the pre-service teachers enrolled in subject HF 2 obtained in Stage 2 is discussed.

From the analysis of the pre-service teachers' perceptions about the relation between the hierarchical organization of the CM and the construction of the HS, Stage I of the research, seven categories were obtained. Among them, six (categories from C1 to C6) are considered aligned with the relations established between CM and HS in our theoretical background (Table 1). These categories are formulated and their definitions appear in Table 3. Following, each category shall be discussed and aspects of HS concerning them shall also be presented.

Category C1 - *The hierarchical organization of the concept map allows showing the improvement of concepts in the HS*, which may be observed in the following data, concerning Student 1: "In HP the concepts improve; increasing the level of importance of understanding certain subject" (Student 1). Such category is reflected in the process of concept specialization that may be observed by the hierarchical organization of the CM. Less elaborated concepts and theories, such as *impetus*, for example, give origin to more elaborated concepts and theories, such as the principle of inertia.

In case of category C2 - *The hierarchical organization of the concept map allows showing the level of importance of concepts in the HS*, it is observed when different concepts share the same hierarchical level, depending on the understanding of who constructs the CM. Thus, concepts such as speed and force may be considered equally important in the historical elaboration of knowledge or very distinct in importance. In the first case, they are in the same hierarchical level; in the the second one, in different hierarchical levels. C2 may be illustrated in the data "The concepts are disposed in order of importance [.]" (Student 1). As it may be observed in the case of Student 1, it was possible to identify categories C1 and C2 in his answer. The presence of data concerning more than one category in the answers provided also occurred with other pre-service teachers.

Category C3 sets *The hierarchical organization of the concept map allows establishing relations between more general and more specific concepts in HS*. Student 5 expresses such understanding in his answer: "[.] hierarchy is organized (from bottom to top) in a way to place the most general concepts on the top of the CM and detail it with the following concepts". This comprehension is reflected in CM in which most general concepts, such as movement and rest, serve as the basis for the development of most specific concepts, such as speed and acceleration. It is worth highlighting that the definition of what is general or specific belongs to the mapper. For example, it may be considered that concepts such as movement, rest, and inertia address a law of inertia (considered, in this case, as most specific) or that they derive from it (considered, in this case, most general). The two interpretations are admissible and are the results of the way the mapper understands the general concept table.

Category C4 sets *The hierarchical organization of the concept map allows bringing answers to the focal question showing different perceptions along HS*. Student 8 states that "the hierarchical organization of the concepts makes it possible to hierarchically present the answer to the focal question given by HP". Category C4 corresponds to the possibility that, from very general concepts, such as the universe or movement, we come to natural laws much more general, going through different "paths" along the hierarchical organization of the CM. For example, the issue of causes of the movement may be explained by Newtonian mechanics without resorting to natural elements of Lagrangian mechanics and vice-versa.

**Table 3: Categories emerging from the conceptions of the pre-service teachers about the relation between the hierarchical organization of CM and the construction of HS**

| Category | Nomenclature | Definition |
|---|---|---|
| C1 | The hierarchical organization of the concept map allows showing the improvement of the concepts in the HS | From the process of hierarchical organization of the concepts in the concept map, it is possible to present how certain subjects of HS were improving from the relation with other concepts and/or from the differentiation between them. |
| C2 | The hierarchical organization of the concept map allows showing the level of importance of concepts in the HS | From the process of hierarchical organization of the concepts in the concept map, the mapper may present the level of importance given to the concepts in the HS. |
| C3 | The hierarchical organization of the concept map allows establishing relations between more general and more specific concepts in HS | From the process of hierarchical organization of the concepts in the concept map, it is possible to highlight that more general concepts of HS serve as basis for the development of more specific concepts, highlighting conceptual relations. |
| C4 | The hierarchical organization of the concept map allows bringing answers to the focal question showing different perceptions along HS. | From the process of hierarchical organization of the concepts in the concept map, it is possible to understand and bring answers to different questions in the HS. |
| C5 | The hierarchical organization of the concept map allows classifying and associating the characters of HS to the knowledge they elaborated. | From the process of hierarchical organization of the concepts in the concept map, it is possible to make relations between the concepts and thinkers, scholars, or scientists that developed them and/or gave the basis for such construction. |
| C6 | The hierarchical organization of the concept map allows presenting the dynamics of the knowledge construction in the HS. | From the process of hierarchical organization of the concepts in the concept map, it is possible to highlight that the construction of the concepts in the HS does not necessarily follow a chronological order, but many times assumes a dynamic that involves different levels of hierarchy of concepts and relations between concepts of a same hierarchical level. |

Category C5 sets *The hierarchical organization of the concept map allows classifying and associating the characters of HS to the knowledge they elaborated.* This may be exemplified with data from Student 11: “In HP this organization is important to classify and associate the characters to their discoveries [.]” This comprehension reflects in a CM that, long its hierarchical structure, the concepts are derived from scientists who elaborate them, or the concepts themselves lead to the designation of its formulator. For example, the 3 laws of movement may be in a hierarchical level inferior to Newton or the 3 laws may derive from the scientist, which would be in a more inferior level in the CM.

At last, category C6, which states *The hierarchical organization of the concept map allows presenting the dynamics of the knowledge construction in the HS,* may be illustrated by the following:

*In the history of physics, the process of hierarchical organization allows presenting complex problems in an organized and hierarchical way, according to experimental and theoretical contributions of a determined line (of thinking), aiming to create or formulate new concepts, after all, we know that views of the world go changing with time and that problems go specifying according to the way they approach or back away from the view of the world established at the time the subjects are being studied (Student 14).*

Category C6 corresponds to how hierarchical organization may reflect the dynamics of knowledge construction. In the HS, new problem situations and new experimental or theoretical results (most specific) allow testing the adequation of the theories (most general), confirming or reformulating them, making them even more general, one way or the other. We may mention, as an example, the development of Einstein’s special theory of relativity. Over more than 200 years ago, Galilean relativity was presented as a general theory, exactly because it perfectly fitted with Newtonian mechanics. Therefore, in a CM elaborated in the scope of classical mechanics, Galilean relativity would be in a hierarchical level superior to the Newtonian mechanics.

However, in the context of electromagnetism, the constant of light speed indicated that Galilean relativity, as a general theory, needed to be reviewed. Special relativity was formulated at the beginning of the 20$^{th}$ century, as a generalization of Galilean relativity. Therefore, in a CM made considering the knowledge of physics, in the scope of mechanics, until the 20$^{th}$ century, Galilean relativity would be in a hierarchical level inferior to special relativity.

The hierarchical organization of the concept map allows HS to be presented chronologically. This category was observed in the data of 40% of the students investigated (6 of the 15 pre-service teachers), as, for example, in the case of Student 6: [.] the hierarchical organization of concepts in the history of physics allows [.] the most specific solutions and theories, developed over time, to be presented in a way to keep the sense and the chronology in which they were presented.

Such category does not keep relation with the conception of science development defended by us in this work or with the CM structure, in which the knowledge is disposed from the most general (higher) to the most specific (lower), in hierarchy level, and without considering a chronology relation among them.

Although thinking of the hierarchical organization as chronology may be mistaken, the presence of this category highlights this may be the way the student organizes his thoughts. This fact may also be influenced by the way knowledge was presented and by the nature of HS knowledge, in different moments along history. Cornelis (2011) points out that it is common for HS courses to present historical knowledge chronologically, leaving conceptual bridges and relations among events apart, which reinforces this conception for the students. The subjects HF I and HF II are structured this way, which may have influenced for the presence of this category, which links hierarchical organization with chronology. However, the presence of the categories C1 to C6 is an indication that the pre-service teachers contemplate other possibilities of relations between hierarchical organization and CM, beyond chronology. This profile initially observed shall also be investigated in the second stage of the research.

*Stage II - Validation of the Categories*

Concerning the categories elaborated in the first stage of the research, the levels of agreement expressed by twenty-eight pre-service teachers were analyzed and developed in Stage II. Such categories considered were from C1 to C6 and also the category. *The hierarchical organization of the concept map allows HS to be presented chronologically*. The analysis was made using the Likert scale as a tool, so that the value 1 presents total disagreement, value 2 partial disagreement, value 3 neutrality, value 4 partial agreement, and, value 5 total agreement.

The corresponding sentences were constructed based on the categories, but, in some cases, express the opposite of what is affirmed in the category. For example, C1 (the hierarchical organization of the concept map allows showing the improvement of the concepts in the HS) is expressed by the following sentence: The hierarchical organization of the concept map does not allow showing the improvement of the concepts in the HS. In this case, the expectation was that the pre-service teacher attributed value 1 (totally disagree) when expressing his level of agreement with this sentence. Such resource was used in some of the sentences with didactical purpose once the instrument of data collection was part of an assessment activity of the pre-service teachers and also to avoid the influence of answers by them. Equally, it was also expected that value 1 was attributed by the pre-service teachers to the category *The hierarchical organization of the concept map allows HS to be presented chronologically*, which is identically expressed in the sentence assessed by the students.

The sentences analyzed by the pre-service teachers and the answer expected in the Likert scale for each of them are presented in Table 4, as well as the number of pre-service teachers that provided the expected answer. In the data analysis, it was considered that the disagreement was expressed by the choice of value 1 or value 2, while the agreement was expressed by the choice of values 4 and 5.

From the data presented in Table 4, it is possible to realize that, in a general way, the categories are validated. It is necessary to discuss more carefully, however, the result associated to the sentence "*The hierarchical organization of the concept map allows history of science to be presented chronologically.*" Although this sentence expresses a conception that does not keep a relation with our referential or with CM structure itself, it showed up in the first stage of the research. The results of this stage indicate that only 18% of the pre-service teachers acknowledge this mistake, while around 70% of the students (who totally or partially agree) do not understand it as a mistake.

**Table 4: Sentences for the validation of the categories of analysis and expected answers in the Likert scale**

| Sentences examined by the pre-service teachers, concerning the categories of analysis | Categories of analysis | Answers considered right in the Likert scale | Quantity of answers considered right |
|---|---|---|---|
| The hierarchical organization of the concept map does not allow showing the improvement of concepts in the history of science. | C1 | Totally disagree (1) and disagree (2) | 27 out of 28 |
| The hierarchical organization of the concept map allows showing the level of importance of the concepts in the history of science. | C2 | Totally agree (5) and partially agree (4) | 21 out of 28 |
| The hierarchical organization of the concept map does not allow establishing relations between the most general and most specific concepts in the history of science. | C3 | Totally disagree (1) and disagree (2) | 25 out of 28 |
| The hierarchical organization of the concept map allows bringing answers to the focal questions showing different perceptions along the history of science. | C4 | Totally agree (5) and partially agree (4) | 26 out of 28 |
| The hierarchical organization of the concept map allows classifying and associating characters of the history of science to the knowledge elaborated by them. | C5 | Totally agree (5) and partially agree (4) | 25 out of 28 |
| The hierarchical organization of the concept map allows presenting the dynamics of the construction of knowledge in the history of science. | C6 | Totally agree (5) and partially agree (4) | 25 de 28 |
| The hierarchical organization of the concept map allows the history of science to be presented chronologically. | - | Totally disagree (1) and disagree (2) | 5 de 28 |

Therefore, in both instruments of data collection, the idea that CM allows HS to be presented chronologically is expressed by the pre-service teachers (40% in Stage I of the research and 70% in Stage II). As previously said, we understand that this perception may be attributed to how the student organizes his thoughts and may be influenced by the way this knowledge was presented and by the nature of HS knowledge concerning different moments along history.

## CONCLUSION

This article presented the results of a study that identifies the conceptions of future physics teachers about the relationships between the hierarchical organization of MC and the elaboration of knowledge in HS. Two instruments for data collection were used and applied with students in a physics degree course offered in distance mode by the public system of higher education in the State of Rio de Janeiro, Brazil, in subjects of HP.

The use of CM and, in particular, of the hierarchical organization, may contribute to the presentation of human knowledge systematized in a non-linear form. We considered that because the concepts in a CM are presented from the most general to the most specific ones, regardless of the historical moment in which they were elaborated (Maximo-Pereira et al., 2021). In the present investigation, six categories were obtained and validated, illustrating perceptions of the pre-service teachers.

Based on these data, since our data fit the previous theoretical framework, we conclude that the premise of the study is, in principle, confirmed. However, the conception that the hierarchical organization of the CM allows HS to be presented chronologically emerges expressively in great part of the pre-service teachers statements. It happened in both instruments of data collection used and with different pre-service teachers. To understand this phenomenon, it is necessary to consider that history, as systematized and schooled human knowledge, bears a strong temporal component, connecting facts, people, and places, in general, chronologically. Therefore, the didactical materials and the subjects of the degree course about HS tend to be organized following a chronological view about the elaboration of scientific knowledge.

Such a fact may generate the understanding that scientific development occurs linearly. It would mean that prior concepts would always be overcome by the next ones or that the most recent knowledge would always and necessarily deny the oldest. In both cases, HS itself provides us examples that contradict these two logics. For instance, we have the caloric and phlogiston theories. They were alternately basing human comprehension about the nature of heat. Another example is the cosmological constant, which, since its proposition, in the beginning of the 20th century, sometimes appeared in cosmological models to explain the evolution of the Universe (Partington and Mckieprado, 1937; Prado and Carneiro, 2018; Chang, 2003; Straumann, 2022).

The main contribution of these results to science teaching concerns the structure of HS course. A HS course planned in a non-linear or chronological way may be an important step for the promotion of new forms of conceiving the development of scientific knowledge in HS. Those new forms are necessary for future teachers. We point out that the discussion about episodes of HS may be a possibility in this direction, because ideas and concepts with different possible levels of hierarchy sometimes are mobilized by the current theories, sometimes are replaced by new formulations, such as those aforementioned.

However, some of the pre-service teachers investigated, even in a subject that linearly presented themes of the HS, were able to realize that the hierarchical organization of the CM allows the knowledge to be organized from the most general to the most specific ones. This relation between CM and HS via hierarchical organization, made by the pre-service teachers, may be indicative that it is possible to present the scientific knowledge in the HS to the pre-service teachers without necessarily using the chronological order. Therefore, it is considered that one of the implications of the work is the use of the CM in subjects of HS that have a more "traditional" structure for the presentation of HS. It is considered that the use of the CM may contribute to the students associating the HS concepts in a non-chronological way but in a hierarchical order.

Accordingly, a course about HS that uses the technique of conceptual mapping and associates it with the elaboration of knowledge in the HS allows the pre-service teachers to initiate the development of the comprehension that it is possible to present and associate scientific ideas in a non-linear and non-chronological way. This conclusion occurs even in a subject that presented the knowledge chronologically, which suggests the potentiality of the CM for this important task of reorganizing the relations between knowledge. Thus, another direct implication of our results is the possibility of organizing a HS course based on the structure of a CM and not according to a timeline. In this case, the professor could have a CM of the concepts and phenomena that would be studied in the HS courses. This CM, which could be prepared by the professor himself, would allow him to present the subjects of the discipline according to some hierarchical organization between knowledge. This fact would contribute to a less restricted and linear view of the development of scientific knowledge on the part of undergraduate students. Opportunely, we intend to investigate whether and how the understanding of pre-service is modified if submitted to a course modeled from the perspective just described.

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