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Abstract

Time is a concept of historical, social, cultural, philosophical, artistic, economic, technological, scientific relevance. Time assumes different meanings in the Sciences, especially in Physics, acquiring fundamental importance in different physical contexts. However, in both high school and college Physics courses in Brazil, time is usually treated as an abstract mathematical parameter to the detriment of recognizing its different meanings, domains of validity, and historicity concerning its genesis. Such treatment of the concept of time leads us to believe that these more particular notions would probably be present in the conceptions within the complex conceptual profile of future Physics teachers in training. We interviewed preservice physics teachers to investigate this hypothesis in physics teacher education. To categorize students' conceptual profile zones, we developed the Concept Polysemy Organization Matrix (POM) based on the dimensions of the complex conceptual profile model and the genetic scales of Vygotsky. As a result, we start to structure future Physics teachers' conceptual profile of time, identifying a myriad of meanings of time through POM. Beyond that, we verified that future physics teachers' dominant meaning of time is numerical since their main formation activity in physics teacher education reinforces abstract mathematical-physical problem-solving.

Introduction

Time is what honest clocks measure. Honest clocks are those that uniquely assign a real number to each pair of events close enough. (Matsas, 2017)

Time is a rich, primitive, multifaceted concept that sustains and is sustained in its multiple meanings by various human activities (Strang, 2015; Fabian, 2014). We experience time within our bodies, but we also identify it in the environment and at different scales. For instance, we experience duration with the appearance and the disappearance of thoughts and feelings. Periodic variations in our organisms, which cause us to be hungry, sleepy, thirsty, cold, also offer us temporal perceptions. Such a myriad of meanings is realized within chains of activities developed and maintained throughout human history. Thus, establishing a definition of time from a cultural-historical perspective is complex, given the wide range of meanings of the concept. From the historical dialectical materialist perspective, concepts can be expressed as definitions if considered in their historical movement. The meanings of concepts are not limited by and depleted in a specific historical context but are continuously produced in different contexts, transforming and being transformed by human activities.

Time assumes particular and fundamental importance to support a conception of reality, considering the context of physics (Ellis, 2008, Cramer, 1995, Whitrow, 1991, 1967, McCrea, 1977). The rigorous physical definition of time presented in the epigraph supports most physical theories that consider the homogeneity of time and the isotropy of space. Such a definition is quite technical, sophisticated, and precise, and to be understood is necessary to know very particular contexts and activities in physics research.

This extremely synthetic definition does not account for the complexity of the historical development of the concept of time. For instance, even considering the context of physics theories, this definition does not contemplate the thermodynamical aspects of the physical phenomena since time irreversibility was not included. Besides, beyond physics, considering the axiological dimension of the conceptual profile of time (Sodré, 2017, Mattos, 2014), other meanings escape from this definition.

The socio, cultural and historical genesis of the concept of time shows its richness and polysemy and invites debate about its origins. Furthermore, it allows establishing the limits of the domains of validity of the concept and the theories supporting it, a discussion that rarely occurs in undergraduate courses. Including the conceptual profile of time in physics teachers' education courses would make future physics teachers better mediate the scientific zones of time and other zones present in primary education students' daily lives. Then the need to introduce a broader reflection on this fundamental concept into scientific education in undergraduate physics courses.

Regarding physics teaching didactic materials, few pedagogical works propose reflecting on the concept of time in their physics textbooks, both in primary and higher education. In general, the approaches denote time only as a unit of temporal measurement. The concept is used only as an abstract numerical parameter in this case. In Brazil, most teachers do not introduce discussions beyond those textbooks suggest, most based only on the contents cast by the entrance exams (Souza *et al.*, 2016; Crochic, 2013; Karan *et al.*, 2006; Martins, 2007).

Given the relevance and breadth of the concept of time, and the need to introduce conceptual discussions in physics teacher formation, it is important to investigate the preservice Physics teachers' conceptions of time. Our primary hypothesis was that such conceptions would be more associated with an abstract and mathematical meaning of time, mainly because the degree course would reinforce the concept of time as a mathematical parameter. Other meanings would remain limited even though they could be introduced throughout the physics teaching degree (specifically thermodynamic and special relativity disciplines).

The present work started from previous research (Sodré, 2017), where (i) some syllabi of the Physics Teaching Degree curriculum were examined to investigate the conditions in which the different meanings of time are introduced. The analysis of the Physics Teaching degree curriculum consisted of evaluating the dominant physics content of the course. 63% of the disciplines of Physics Teaching degree correspond to the domain of Classical Physics, mainly produced until the end of 1900. In this domain, the concept of time used corresponds to a single numerical sequence, linear, uniform, homogeneous, independent of the referential. (ii) The approaches to the concept of time in the most used textbooks in the introductory disciplines of the degree were surveyed. Concerning this bibliography, the sample analyzed was composed of basic physics textbooks used in the first two years of the degree. All textbooks emphasize the mathematical aspect of time and propose a considerable number of exercises since problem-solving activities are still considered essential for learning physical theories in physics education. It was also found that most of these didactic materials present physics devoid of historical elements. (iii) Interviews with the Physics teachers of the degree were conducted to identify how the concept of time is usually taught in classes. The interviews with four teachers of the degree course exposed that the main purpose of teaching the concept of time is for the student to manage it mathematically, mastery achieved through problem-solving activities. The teachers agreed that time is taught as a mathematical parameter since the beginning of the course, being discussed only in the latest moments of the latest disciplines (e.g., Relativity); unfortunately, time is also taught as a mathematical parameter. To these teachers, time should be taught as an independent variable since all other variables will depend on it, and "you have to look at time as one of the first things they see in the course, (...) further on (...) this will already be something so natural (...) it becomes a more abstract subject, it becomes internalized by them … and being used more naturally." (Teacher 1 *apud* Sodré, 2017, 69). Beyond that, teachers did not see the need to discuss the concept philosophically. Finally, (iv) a non-exhaustive study on the evolution of the meanings of time in the history of science was carried out. Then, based on these previous results, this work introduces an instrument to structure the complex conceptual profile of time of future Physics teachers: the Concept Polysemy Organization Matrix (POM).

Theoretic-Methodological Framework

Complex Conceptual Profile

One of the most important aspects of science teaching and learning is how people learn concepts. The investigation of the learning process of scientific concepts has a tradition that goes back to early modern Psychology, investigating the use of physical and mathematical concepts (Ozdemir, 2004). From the 1970s onwards, the idea that learning was dependent on students' prior knowledge was more clearly established. Then, the research focused on alternative conceptions, investigating the conceptual framework of individuals before specific scientific concepts were formally taught.

One learning model gained more attention being adopted for a significant part of the science education community: the conceptual change model (Posner *et al.*, 1982). The authors proposed the conceptual change model to understand how to change alternative conceptions through teaching scientific conceptions. The model represents learning as the replacement process of the student's previous conceptions with scientific conceptions. The conceptual change model was premised on the idea that "conflictive conceptions cannot be, simultaneously, plausible for a person" (Hewson & Thorley 1989, p. 543). However, even after extensive conceptual change strategies, conceptual substitution was deconstructed since students' alternative conceptions are not replaced by the scientific ones (Galili & Bar, 1992; Tao & Gunstone, 1999). Beyond that, previous conceptions were not changed and coexisted with scientific conceptions (e.g., Linder, 1993, Duit & Treagust, 2003), opening the floor for other conceptual learning models, particularly those considering the possibility of coexistence between different meanings of the same concept (Mortimer, 1995, Linder, 1993).

Mortimer (1995) proposed that each individual has a set of different representations of a given concept. The different meanings would be organized in different zones that, in turn, would compose the profile of a concept. The coexistence of different ways of thinking on a concept through different contexts indicates different relationships established in experiencing the world, so the meanings differ epistemologically and ontologically. In this perspective, the evolution of students' ideas can be understood as the evolution of conceptual profiles, where new concepts learned establish relationships with other concepts and have their profile zones modified. Nevertheless, researchers in science education continued to review the notion of the conceptual profile, and advances in the previous perspectives pointed out by Mortimer (1995) resulted in the proposition of a Conceptual Profile Theory Theory (Mortimer & El Hani, 2014). Among the contributions given, we are aligned with the perspective of the complex conceptual profile (Mattos, 2014).

Mattos (2014) introduces complex systems ideas and Cultural-Historical Activity Theory (CHAT) framework to deeper understand the relationship between conceptual profile zones and context (Rodrigues and Mattos 2007; Mattos, 2014; 2019). In this perspective, the context was considered a complex system composed of several hierarchical levels of elements in feedback interaction, and the cognitive structures of the subjects reflect the complex structure of the world. In this way, each conceptual profile zone refers to the meaning of a concept in its specific context of use.

Beyond the epistemological and ontological dimensions originally proposed by Mortimer (1995), the axiological dimension was introduced as constitutive of the conceptual profile zones (Dalri, 2010; Mattos, 2014). The epistemological dimension refers to the production of knowledge, which deals with "how" a subject knows an object. The ontological dimension deals with the nature of objects, referring to "what is" the object and reflecting in the polysemic condition of the words embodying concepts, whose meanings depend on the contexts and activities in which the concepts are developed. Finally, the axiological dimension refers to the values and purposes attributed to objects. Refers to the "why" of the motivations, necessities, and choices according to which subjects employ the concept. Based on CHAT, Mattos (2014) points to the context as the center of the analysis of the conceptual profile development and takes the activity as a unit of analysis of the learning process. The change is due to Leontyev's (2009a, 2009b) principle of the dialectical unit of human consciousness and activity, as we will see in the next section.

CHAT and the Concept of Time

Different scholars have built the CHAT since the beginning of the 20th century. The most prominent figures are Vygotsky (1997) and Leontyev (2009b), that later had their works systematized (e.g., Engeström, 1987). According to Sannino, Daniels, and Gutiérrez (2009), to account for the complex cultural and historical structure of the formation of active subjects, CHAT seeks to analyze human development within human activities, considering anthropological, sociological, historical, psychological, and linguistic aspects. Unlike Vygotsky, who considers meaning as the unit of analysis, CHAT's unit of analysis is human activity. Then, human activity is considered the primary and minimum unit capable of expressing the totality required to understand human development.

The central CHAT thesis is the dialectical association and reciprocal determination of activity and human consciousness. Then, the typically human potentialities can develop and transform the world through activity, consciousness, and personality. The human activity dynamic is forwarded by contradiction, which should be overcome by producing new cultural artifacts, and, consequently, producing new needs, new conditions of existence, and new contradictions (Sannino Daniels, Gutiérrez, 2009). Activity is triggered by needs that create motives that are concretized in an object. Thus, the subjects' actions are oriented towards the object of the activity. Every activity consists of a set of coordinated actions with specific purposes. In turn, the actions have conditions – operations – under which they can develop.

Even if taken as a unit of analysis, activity should not be understood as hermetic and homogeneous. On the contrary, every activity is open, linked to the complexity of the labor division and modes of production of the subjects. Thus, the coordination of actions and the conditions of their achievement are part of a hierarchical dynamic system in continuous transformation. It is also important to clarify that the activity components have multiple mediations in circular causality and mutual determination. Depending on the level of analysis, the activity can be at a lower or a higher hierarchical level of the system of activities, expressing different structure degrees of complexity. Regarding a concrete activity structure, each hierarchical level - operation, action, and activity - can be seen as a unit of analysis if each one can be understood as an activity (Mattos, 2019).

Regarding our object of interest - time, CHAT's contribution helps us to highlight and explore fundamental aspects of its meaning. Activities have contexts where different zones of the conceptual profile are manifested. Due to the complexity of the human activities network, which continually evolves, concepts have multiple meanings (Engeström, 1987, 2001). Concepts, as conceptual profiles, dialectically unify consciousness and activity (Leontyev, 2009a, 2009b). This fundamental relationship comes from the thesis that there is a "common structure of human activity and individual consciousness" (Leontyev, 2009a, p. 98). Before Leontyev, Vygotsky pointed out that it is necessary to consider practical and objective life to understand a concept (Lago & Mattos, 2021).

From the CHAT perspective, concepts simultaneously are supported by human activities and support these very activities (Lago & Mattos, 2021). That is why we look at the history of science, searching for some human activities and their developments, particularly those involved with the genesis and support of different meanings of time, since it is where different consciousness, and consequently, different concepts of time develop. For instance, in ancient agricultural European communities, time was associated with the movements of the stars and the environmental luminosity and temperature variations. Time was associated with periodic phenomena in nature and understood as cyclical and qualitative. This meaning was connected mainly to agricultural activity – the system of activities related to agriculture. Thus, in those communities, the concept of time was ontologically associated with the movement of the stars and was, simultaneously, an instrument guiding activities such as sowing, planting, harvesting, and irrigation. Over the years, the need to coordinate the various activities - p.e. agricultural, religious, festive - led to the development of instruments produced within those human activities systems. Time was synthesized - human activities were synthesized and crystallized - in calendars and clocks.

With the production of these instruments, new mediations and new meanings for the concept of time were created. At this point, time came to be understood as continuous, measurable, and countable, independently of the observation of the movement of the stars (Elias, 2007).

Then, concepts' meanings are constructed throughout history and express the development of mediations within human activities. Time has its meaning complexified since the system of activities has also been complexified. From this complex dynamic view of concept development, it is possible to say that, among the different concept meanings (or different conceptual profile zones), the adequate meaning to be used depends on the activity (or context) in which subjects are involved. The mediations among the activity's subject, community, and object express the resonances between the conceptual profile zones and the context (Mattos, 2014). Then, the diversity of conceptual profile zones is related to the different ways the activities are stabilized and, consequently, how the meanings are stabilized. Therefore, since the appropriate meaning in each context is developed within the particular activity, we connect the complex conceptual profile model to CHAT.

Considering Elias's (2007) example of the correlations between the movement of the stars and agricultural timings, it is essential to return to Leontyev's (2009a) central thesis of the dialectical determination of human activity and consciousness. The different meanings of time result from the dialectical joining between human activities and consciousness. In the subject-object-community interaction, language and meanings emerge, resulting in new objects, i.e., new mediations and new consciousness developments. More generally, those societal agricultural activities constitute the different ways of being within these socio-cultural-historical situations.

Method

On the Survey of the Samples' Complex Conceptual Profile

Some authors have proposed instruments that allow the identification of the different dimensions of the conceptual profile, whether in the case of the "Epistemological Matrix" (Sepulveda, 2013) or the "Semantic Matrix" (Bego *et al.*, 2021; Reis, 2018). In general, for the construction of the conceptual profile of a concept, the proposed methods are based on a non-extensive survey of the historical development of the concept; a survey on related science teaching research literature; a survey about students' previous conceptions about the concept; the use of data from interviews with high school and college students; and data from discursive interactions in the classroom. The authors raised epistemological and ontological aspects involved in the meaning of this concept, characterizing the instrument as a tool to organize the concept polysemy and identify epistemological and ontological commitments, from which the zones of a profile are built (e.g., Sepulveda, Mortimer & El Hani, 2013). This perspective intends to construct a conceptual profile, which can be considered general and used as a parameter in any teaching situation of the profiled concept (Mortimer & El Hani, 2014). In our case, we intend to limit the investigation of the profile to certain enunciative conditions of physics teachers in training, in their relationship with the training activities to which they are subjected, and the conscious awareness they have of the different dimensions and zones of the conceptual profile of time. This makes it possible to understand more clearly, in a concrete situation, the development of the conceptual profile in the educational process.

Therefore, to investigate the preservice physics teachers' conceptions of time, we interviewed undergrad students of the Physics teaching degree and elaborated a proposal to evaluate their conceptual profile of time. We sought to formulate questions that would take participants to the contexts of undergraduate courses, their everyday life, and history. We used different deixis, allowing the preservice teachers to identify elements of their most immediate context or others contexts, such as those related to different societies and cultures. Our objective was to identify whether the interviewees utter the concept of time as a socio-cultural-historical construction. Furthermore, we used terms emphasizing the dimensions of the complex conceptual profile, introducing questions about how time is known (epistemological dimension), what is its nature (ontological dimension) and what values and purposes are attributed to it (axiological dimension).

Our instrument supports classifying the complex conceptual profile's dimensions and socio-cultural-historical aspects related to a genetic analysis. Such analysis considers human development through the physical transformations of the species taking place, at their own pace, over the millennia and the psychological development resulting from experiences within an organized society based on work. Thus, for Vygotsky, any human psychological phenomenon must be interpreted as arising from the interaction of processes that occur at different genetic levels throughout human life. The totality of processes has been represented through four scales (or genetic domains) that express the different time and space scales in which human development occurs. Wertsch (1985) summarizes the Vygotskyan perspective by proposing four genetic domains: *phylogenetic, ontogenetic, historic sociocultural* (or sociogenetic), and suggesting the *microgenetic* domain. Different biological, historical, and social forces of development operate at such scales, each with its own set of specific explanatory principles (Vygotsky, 1997; Leontyev, 2009a). We interpret human development as a continuum of development processes, occurring simultaneously but with the different passage of time (time scales).

Taking these theoretical aspects into account, we propose an instrument called the Concept Polysemy Organization Matrix (POM). It is based on Vygotsky's genetic method (Wertsch, 1985) and the complex conceptual profile dimensions (Mattos, 2014). POM helps to identify relationships between the genetic plans and the complex conceptual profile dimensions in the interviewees' discourses. Based on POM, we organized zones of the conceptual profile of time - whether related to the movement of the stars, the measure of the clock, the sensations of an organism, climate changes - with different time natures (cyclical, linear, with shape or structure), different values and different purposes for time. POM development involved elaborating criteria to identify each genetic level, distinguishing different contexts accessed by students. Regarding the microgenetic plan, we considered more immediate events in time and space – most of the situations were experienced by the subject at home or school. Regarding the sociogenetic plan, we considered more long-lasting events related to situations in the community and the society in which the student lives. Regarding the ontogenetic plan, we considered even more long-lasting events, that is, situations in the history of societies. Finally, regarding the phylogenetic plan, we considered events related to the history of the human species.

Data Collection and Participants

We interviewed students attending a four-year degree course in Physics Teaching at the Institute of Physics of the

University of São Paulo in 2016. Fifteen students composed the sample: three students from the first year, four from the second year, four from the third year, and four from the fourth and final year. The fifteen participants, prior to participation, have signed a written informed consent document and have their personal information preserved. A longitudinal investigation was not possible, and we could not follow each subject throughout their undergraduate years, identifying the development of their concept of time. To deal with this impossibility, we cast a sample of the fifteen students chosen according to the following conditions: (a) the participant should be attending his first undergraduate course; (b) the participant should express the intention of becoming a teacher; (c) concerning other activities, their undergraduate education should play a lead role in their lives. Such criteria are intended to ensure that, even within a complex chain of activities in their life, the Physics Teaching degree course should deliberately constitute students' main activity and be engaged in the course. They should show a similar dedication to the disciplines, follow the same weekly average of study time and use the same didactic materials. We aimed to obtain a qualitative homogeneity among the participants of each year. The criteria allowed us to select students similarly involved with the activities of the degree course. Thus, the same educational instruments, rules, and division of labor mediated the different educational stages within the sample.

Results and Discussion

The categories of analysis were elaborated based on the analysis of the transcripted interviews. Initially, thirteen categories were established, and, at last, they were synthesized into eight broader categories. Table 1 presents the thirteen initial categories in the first column; in the second column, their characteristics; in the third column, how they fit into the final eight categories. The characteristics highlight one or more dimensions of the complex conceptual profile that we consider to be the most relevant within each category.

Table1. Summary of First and Second Categorizations and their Characteristics

1st Categorization	Characteristics	2nd Categorization
Absolute Time	Time is considered independent of matter and energy. It is external to man and flows without ceasing. Ontological dimension: independent, absolute time.	Absolute Time
Irreversible Numeric Time	Time is related to its measurement. It is measurable, numerical, linear, and irreversible. Epistemological dimension: time as a quantitative measure. Ontological dimension: linear, cyclical and irreversible time.	Numeric Time
Time Calendar	Time is related to the organization and coordination of human activities and historical events, which occurred cyclically. Epistemological dimension: time associated with different types of clocks and calendars.	
Time as Transformation	Time related to change, movement, transformation. Epistemological dimension: time as transformation. Ontological dimension: time is transformation.	Time as Transformation

1st Categorization	Characteristics	2nd Categorization
Time and Light	Time is related to luminosity, an alternating light and dark, due to the rotation of the Earth and the different seasons. Epistemological dimension: time expressed in changing light.	Time of Synergy
Time of The Stars	Time is related to the observation of the movement of the stars. Epistemological dimension: time associated with the movement of the stars.	
Time of The Organism	Time is related to consciousness, spirit, thought, the development of beings, and the internal cycles of the organisms. Epistemological dimension: time expressed in the synchronization between the internal mechanisms of organisms and the changes that occurred in the external environment. Epistemological dimension: time associated with hunger, sleep, thirst, cold. Time associated with consciousness, the appearance of thoughts, memories.	
Time of The Physical Phenomena	Time is related to the knowledge of physics. Category with subdivisions. Epistemological dimension: Time associated with the contents of disciplines or a specific physical context. Ontological dimension: time as an expression of physical phenomena.	Time of The Physical Phenomena
Time of Perception	Time is related to the perception of the passage of events as faster or slower depending on the subject's activity. Time related to religion. Axiological dimension: time as a feeling of passage.	Time of Perception
Time of Enjoyment	Time is related to affections and enjoyment in activities valued by a particular subject. Axiological dimension: time as a subjective value.	Reflection On Time
Time and Purpose	Importance and purpose of learning about the concept of time. Axiological dimension: time as a purpose - to measure travel durations, to produce technology, to allow ideas to "mature", to learn.	
Time In Itself	Mention about the nature of time without defining it through its measurement. Axiological dimension: time as an object in itself.	
Time as Exchange Value	Time as monetary value. This notion pertains to a capitalist society. Axiological dimension: time as an exchange value.	Time as Exchange Value

Our decision to coalesce the categories was based on the study of historical elements on the concept of time. For example, we have considered that Calendar Time and Irreversible Numerical Time could be combined since both categories refer to events that occur sequentially, following a numerical order compatible with the time measured by clocks. However, Absolute Time could not be combined with these categories because it refers to an idea of time that, in addition to being numerical, linear, homogeneous, is independent of energy, matter and human activity.

The categories Time of Enjoyment, Time and Purpose, Time in Itself were grouped under Reflection on Time since they refer to the consideration of the use and purpose of time. They also encompass a reflection on what time is without using a measure to define it. The categories Time and Light, Time of The Stars, and Time of The Organism were grouped under Time of Synergy. The term “synergy” comes from the Greek synergía, formed by the syn (“together”) and ergon (“work”). It means to act together, and it refers to collaboration, cooperation. The category Time of Synergy synthesizes the main idea of these three categories since the concept of time is associated with the stars’ movement that is connected with the climatic (seasons) and the luminosity variations (day and night) of the planet and is generally in harmony with the chronobiology of living organisms. The category name was chosen to allude to the coupling and the mutual harmony between the stars’ periodic movement and living beings’ behavior on Earth.

Thus, the final and broader eight categories established for the analysis of the interviews are Absolute Time, Numeric Time, Time as Transformation, Time of Synergy, Time of The Physical Phenomena, Time of Perception, Reflection on Time and Time as Exchange Value. The POM results were organized into the following figures. We have chosen to highlight Vygotsky’s genetic scales, the complex conceptual profile dimensions, and the eight a posteriori categories in the data organization. During the interviews, the student’s utterances belonging to the intersection between dimensions of the conceptual profile and genetic scales were recorded. The numerical frequency of the identified categories was made from the average number of registers of each category of students of the same year enunciated, mitigating the numerical imbalance among students who over repeated some categories.

Each graph at figures corresponds to either the microgenetic, the sociogenetic, the ontogenetic, or the phylogenetic scales and contains data corresponding to the four stages of the degree course. At the abscissa, the eight a posteriori categories can be found. They are grouped under the conceptual profile’s epistemological, ontological, and axiological dimensions. There is the number of occurrences corresponding to each category at the ordinate.

Figure 1 highlights the microgenetic scale corresponding to the knowledge acquired from experiences closer to the participants (such as experiences that occur in interaction with their families, colleagues, teachers at school, professors at college, etc.). Since students have particular microgenetic trajectories, it is reasonable to associate the growing number of responses categorized as Time of the Physical Phenomena to their progress in the undergraduate course, their dominant activity. As the course advances, students deal with the concept of time in different physics theory contexts, such as gravitation, optics, thermodynamics, electromagnetism, and special relativity.

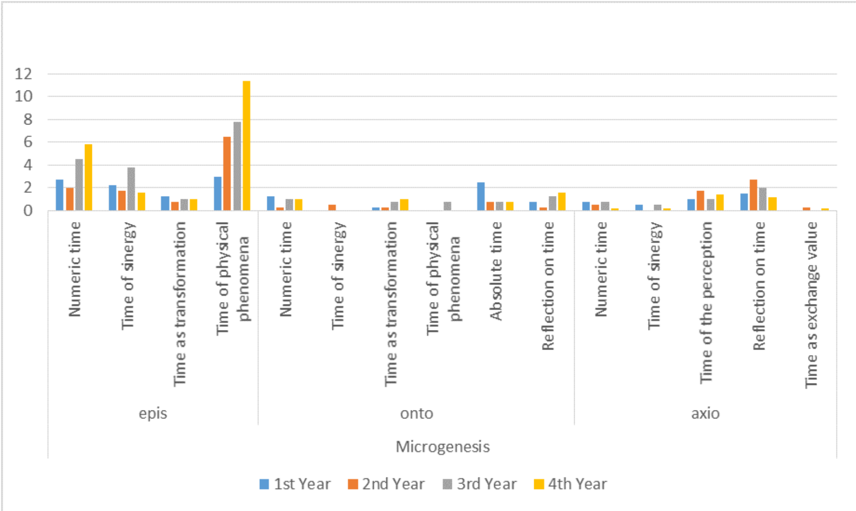

Figure 1. Average of Results for the Microgenesis Section of POM Concerning the Whole Sample

Concerning the first-year students in our sample, the responses classified as Time of the Physical Phenomena typically correspond to the context of classical mechanics (specifically, to situations involving the calculation of time intervals during displacements):

Researcher: What is time?

S9Y1 (Student 9, 1st year): I would say that it is the measurement that we can take with the watch, [...] that we can keep time with some type of equipment, watch, stopwatch, etc.

In this excerpt, the student answers the question "What is time?" in the context closest to their personal experiences, expressing the notion of time as linked to the measurement made by watches and to the duration of displacements. It is worth remembering that, in this article, we are considering Mathematical Time as a merely numerical sequence. At the same time, all four first-year students did not remember having discussed temporal reversibility or the relationship between time and the principle of energy conservation in their classes.

The other interviewed students located the Time of the Physical Phenomena in more advanced contexts such as those related to the disciplines entitled "Physics of Heat" or "Restricted Relativity." Even though they had not attended these disciplines, Students manifested excitement to attend. They were motivated to search for information on the content beyond what was provided in previous undergraduate disciplines.

Comments on relativity were the most frequent, especially among students who had not taken this specific class. Their enthusiasm and freedom to reflect on this subject matter and establish connections, even informally, between the relativistic time and the world were noticeable. It is important to note that only seven students from the third and fourth years attended the special relativity discipline out of all the respondents. In addition, five of these seven students had some discomfort about the meaning of relativistic time, as exemplified in the following excerpt:

Researcher: Do you think that time dilation really happens or is it just theory?

S4Y3 (Student 4, 3rd year): I will be very honest, […] is very difficult to think that time expands, that space contracts. I don't even know how to explain how to look at time that way. How is there a negative time? I don't know [...] is that time within my reach? Actually, this time of relativity exists, but it is not noticeable for us. We, ordinary beings, do not stop to think that it exists. But I don't know [...] can I influence it? […] I don't know if I can have an influence on that time. I'm thinking about the case of the bomb [refereeing to a textbook exercice] that would explode and, if I was going to save the person, how fast did I have to be to get there ... that's crazy!

This answer shows that the meaning of relativistic time appears as a strange thing. Some expressions reveal the difficulty to understand the concept: "we, ordinary beings" and "the case of the bomb […] that's crazy!", pointing to the distance between the situations experienced in everyday life and the "crazy," unusual situations involved in the problems of relativistic kinematics.

Researcher: Can time be changed? How?

S2Y4 (Student 2, 4th year): Changing time ... well, let me think, changing time ... and then we fall into that question of what is time, right? If we can change time ... well ... maybe, if we lived in some other way, maybe time would be different ... if we can change time ... unless, like we learned concerning relativity, if you end up traveling at high speeds, close to the speed of light, you can change time, to you it can be one ... but, change time as a whole, I can't answer.

R: Ah, but then… there are some ways - relativity, you said one!

S2Y4: Yes, but then that time would be for me! It would not be time for everyone. Time for me, I would manage it, time would be one, but for another person who is in another place, who is not traveling, who is standing still, maybe it would be different... time in relation to this two people. Now, if it was in order to change time, if this change was to be valid for the whole universe, then I do not know if we could do this…

Researcher: [...] Do you think there is a time of the universe? That would be time as a reference?

S2Y4: Yes, yes. It would be time as a reference! It would be time as a reference.

Student S2Y4, from the final year, has already studied special relativity and considers the existence of a time as external to humanity ("time as a whole"), which can be taken as a reference, even in special relativity. The enthusiasm concerning relativity, noticeable when the students were in the initial years, seems to wane throughout the course, especially after this long-awaited discipline. This decreasing interest seems to be due to the absence of educational activities directed to discuss the limits and the possibilities of physical theory, a discussion typically reserved, in academia, for specialists.

Still, on the category Time of the Physical Phenomena, we present another excerpt concerning the context of thermodynamics:

Researcher: What knowledge, physical concepts are related to time?

S8Y3 (Student 8, 3rd year): Yeah ... look, okay, let's see if I could tell ... the disciplines in which time appears... in my opinion ... look, those in which it doesn't appear, I'll justify it for you ... [in] thermodynamics time hardly appears like that. "Therm" is interested in thermal equilibrium, not in how long it took for the ice to turn into water, […] I want to know how much energy was transferred … thermodynamics does not include time. Yeah... wave oscillations, rarely, sometimes you calculate the speed of the wave at the top, but not often, the exercise… really, we want to know how much the wave will deform, how much force or... or the oscillation of a period.

The S8Y3's answer points to the predominance of problem-solving activities at the disciplines since the references are always exercises, making it difficult to discuss and understand the concept, its meaning and context of validity. We found that ten participants had already attended the "Physics of Heat" discipline. Regarding the meaning of time associated with irreversibility and entropy, only three claimed to know the "arrow of time" and the association between time and entropy. Most participants who had already attended one or two disciplines involving thermodynamics did not spontaneously address the meaning of time related to entropy or mention the arrow of time in their responses. According to one of the teachers of "Physics of Heat" and "Thermostatistics", the discussion about thermodynamic time is not the focus of these disciplines.

There is a greater concentration in the epistemological and axiological dimensions than the ontological dimension at the sociogenetic scale. In order to explain the breadth of the concept that we were able to explore in the interviews, we will provide examples of occurrences in the categories Time as Exchange Value and Reflection on Time of the axiological and ontological dimensions.

> S9Y1 (Student 9, 1st year): We hear a lot about 'time is money' but [...] people are not concerned with knowing what time is that deeply [...] They just live without questioning it, in my opinion. I believe that with the development of technology, people have a greater understanding of what time is from a particular epoch and, due to that development, they have in mind that they will not live forever and some try [...] to give their best while they are alive and enjoy what they have to do, travel, study, visit other places and... etc.

Next, Figure 2 highlights the results obtained on the sociogenetic scale:

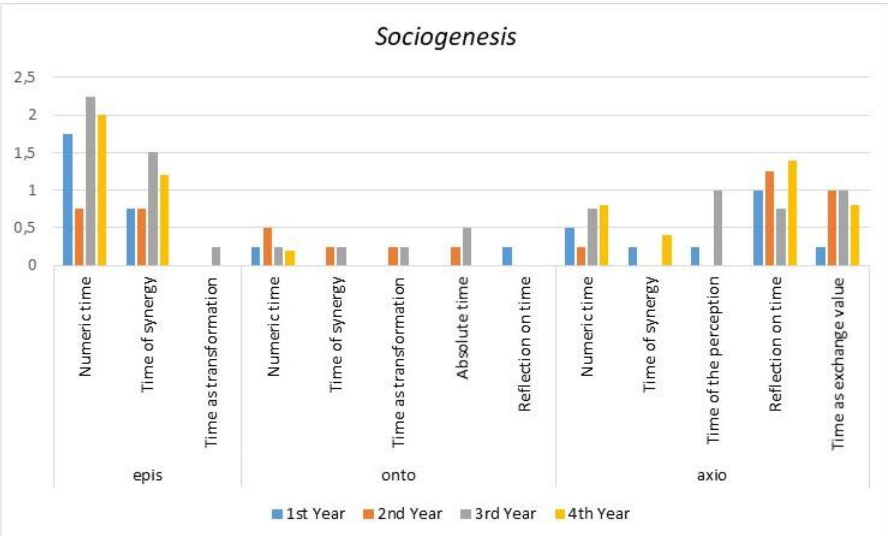

Figure 2. Average of Results for the Sociogenesis Section of POM concerning the Whole Sample

This excerpt illustrates how they conceive time as a value related to money, also considering the relationship between time and what people value in their lives. Therefore, the time introduced was classified in the category Reflection on Time. In the following excerpt, we emphasized the category of Time as an Exchange Value on the sociogenetic scale and axiological dimension:

Researcher: Who most values time in your society and culture? Why?

S4Y3 (Student 4, 3rd year): We are inserted in a capitalist system. I think that, like it or not, every citizen ends up having to... to be very connected to chronological time, needs to work, to earn money, to be able, to eat, to dress, to buy and you have to study, otherwise you will not be hired by the company, to have money, to be able to maintain yourself. So, in this sense of chronological time, I think that, whether we like it or not, everyone who is a part of the system ends up having this concern with time. ... So, whether we like it or not, in our capitalist society everyone, everyone is ... dependent on time.

Figure 3 shows the results obtained at the ontogenetic scale:

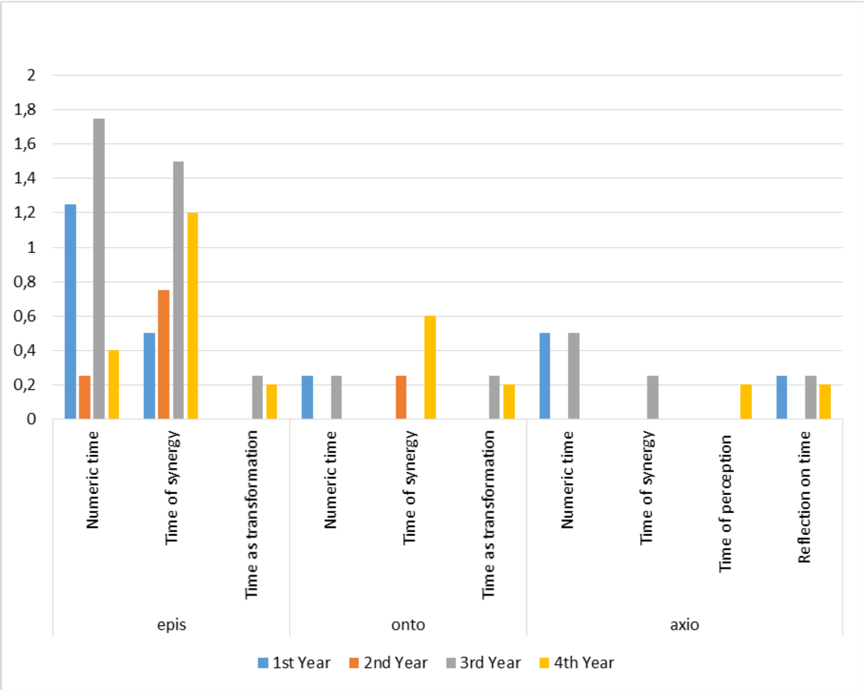

Figure 3. Average of Results for the Ontogenesis Section of POM concerning the Whole Sample

The ontogenetic scale refers to how time was/is known in other societies and cultures. The answers provided by the students were classified mainly in the categories Time of Synergy and Mathematical Time. The following excerpts exemplify it:

Researcher: How could you and people from your society and culture measure time without clocks? Why? Justify.

S3Y4 (Student 3, 4th year): I think we would have to go back a little, think about old societies. Actually, I think that observing and thinking about nature, especially earlier knowledge of astronomy, observing the sun, observing the moon, observing vegetation...

S5Y2 (Student 5, 2nd year): So, we could do it as the ancient ones did, they measured the hours, they put the clock here and as the sun rose and set, growing, shading here, right? They did it like that, I think it's a good example.

The excerpt points to the ontogenetic scale. According to student S3Y4, ancient societies used the movement of the stars and the development of beings (vegetation) as instruments to know the time. Student S5Y2 mentions the projection of shadows on sundials to measure time.

At the intersection between ontogenesis and the ontological dimension, we obtained a smaller number of data from the statements given by students. This result could be explained by the fact that discussing the nature of a concept in another epoch, place, and society requires some consciousness and knowledge about the genesis of the concept. Besides, the study of the history of science seems to be concentrated mainly in Gravitation, a discipline that addresses the history of time in physics, particularly its measurement.

Figure 4 presents the phylogenetic scale:

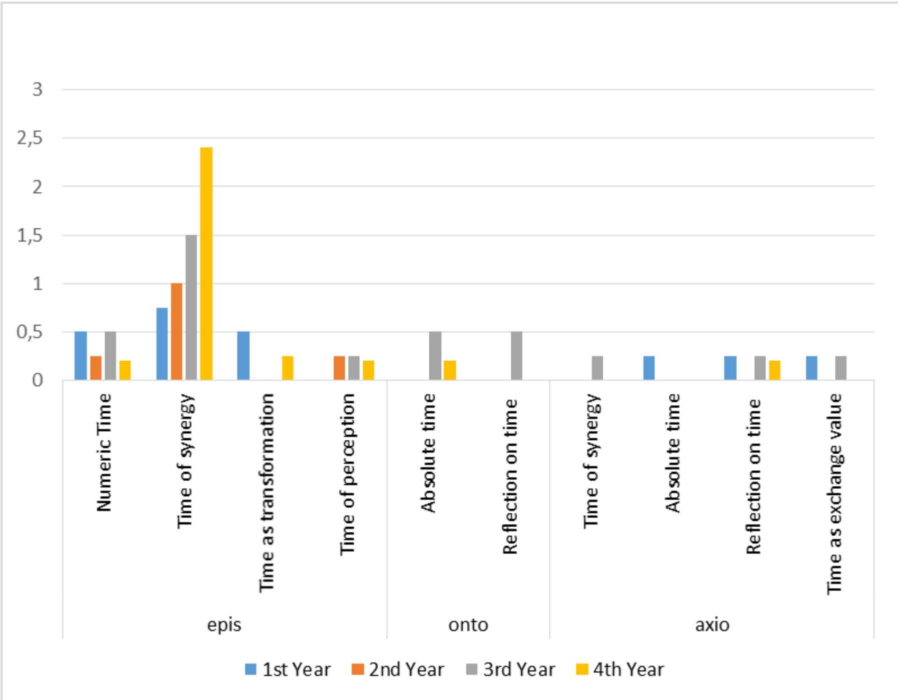

Figure 4. Average of Results for the Phylogenesis Section of POM Concerning the Whole Sample.

The least amount of data was obtained at the ontogenetic and phylogenetic scales if compared with microgenetic and sociogenetic scales. Respectively, the ontogenetic and phylogenetic scales refer to knowledge involving the history of time in other societies and the perception of time considering the human species and other species. The lower number of occurrences registered shows that little attention is paid to the historical elements related to the concept of time in the degree course.

Here are some examples of responses given by undergraduates:

Researcher: There are species of moths that live less than 24 hours. The human species has the ability to live longer. Do you think that our physiology and the fact that we are human influences our understanding of what time is? How? Justify.

S1Y4 (Student 1, 4th year): I don't know if you have already done this, I had a lot of fun, I took a slug, put it here [in a sheet of paper] and I spent a lot of time looking at it. I looked at the clock, and I wanted to see

> how long it took for it to go from here to there. Yeah, I was, like, way too long, I was looking at it...
> Researcher:… but did it want to go there?
> S1Y4: Ah, the slug does not stay still, it is very rare for it to stay still, especially if you sprinkle a little salt behind it, then it starts to move forward. And I kept looking at it, I said: damn it, I take a step and I'm there, this slug, you don't… you can't... so… but then… for the slug, its time... for us it takes a lot to get there [points to a distant point], but not to her ... but not to her, it takes as long as it takes for me or you. I think it would be very difficult for a slug to exist with all the speed it has and with the cognitive capacity we have... because then you can't do anything. Have you ever imagined yourself with our cognitive ability and you can't talk, you can't go to the door, you can't open the book... it is weird, or do you take two hours to open a book, to make this movement? Opening a page is ... it's scary. It is strange, very strange.
> Researcher: ... a physical problem.
> S1Y4: Totally! It would take a little longer for humanity to develop if we had this problem.

In the phylogenesis scale, we seek to consider relationships between the characteristics of living beings (such as human binocular vision, human bipedalism, etc.) and the way they conceive time. The excerpt above presents the relationship S1Y4 establishes between the slug as an organism and his idea of time. One of our criteria for selecting samples was that the Physics Teaching degree course had to represent the dominant activity of the interviewee. The results presented in the four figures show that most of the responses were classified on the microgenetic scale. Since the microgenetic scale encompasses the closest, the immediate context of the participants – including the degree course – the result can easily be understood.

The sociogenetic, ontogenetic, and phylogenetic scales, on the other hand, obtained fewer records. This result is probably because these scales refer to broader contexts, encompassing the interviewees' society, other societies, and the history of humanity, which requires specific historical knowledge. As we will discuss later, in our investigation of the degree course in Physics Teaching, we verified that elements of science history were barely present. Regarding the dimensions of the conceptual profile, the most significant number of records occurred in the epistemological dimension when students talked about time in association with clocks, calendars and physics magnitudes. Moreover, the smallest number of records occurred in the ontological dimension in the face of questions about the nature of time - a subject little discussed in the course.

Concerning the values and purposes attributed to time (axiological dimension), we found an interesting, noteworthy difference respecting the concepts found within the four-year sample. We verified that students attending the first year understand the study of time as intended to achieve immediate and pragmatic purposes, such as calculating the time interval of a car on the road moving from one point to another. However, students of the later years associate other values to studying time during their teacher formation, such as expanding their worldviews.

Conclusions

To investigate the teaching/learning of the concept of time in the physics teacher's education and to analyze the preservice physics teachers' concept of time, we developed the Concept Polysemy Organization Matrix (POM). This instrument investigated the undergraduate students' conceptions of time throughout different Physics teacher course stages. We investigated aspects related to students' values and purposes to time, its nature, and historicity. Besides, we identified the overlapping of levels related to particular meanings of the concept of time in different contexts (such as the familial, academic, or the physical context, and contexts about specific societies). As a result, we concluded that the concept of time most used and exercised in the degree course in Physics Teaching, which is also present in the students' statements, refers to numerical time associated with the measurement of clocks – understood, therefore, only as a numeric variable.

Considering the participants, the future physics teachers privileged the numerical meaning of time, i.e., mathematical time. The lack of discussion about the historicity and validity domains of the concept of time promotes a distancing from broader meanings and the enveloping of numerical and mathematical meanings in school activities. We understand that the meanings of time presented to students can acquire the appearance of purely theoretical, artificial, auxiliary instruments, maintaining a privileged instrumental meaning of an abstract, numerical, mathematical variable. That is, after all, the typical meaning in the problem-solving of abstract mathematical-physical problems - in its turn, the dominant activity in physics disciplines. This is reinforced by the professors of the degree course that emphasized the importance of teaching time as a mathematical parameter of the physical theories. Beyond that, the disciplines' textbooks approach concentrates on the mathematical use of time without considering genesis, historical meanings, or contexts of use.

It is essential to provide to future teachers' connections between physical knowledge and students' lives. The absence of didactic materials or activities presenting meanings for time besides the mathematical dimension make poor their formation, preventing them from having a broader repertoire of meanings and contexts of use of the concept of time. The naturalization of the numerical conception of time finds fertile ground since it is repeatedly experienced during course activities, focusing on physics as mathematical problems. Most of the time, undergraduate students involved in problem-solving activities are faced with the same conceptual profile zone of time – the numerical one, devoid of history and, therefore, not enriched by the most diverse human mediations. These activities do not provide room for debate in which different meanings and mediations could appear, even though a repertoire of different meanings and mediations is important for the future teacher to handle the diverse meanings that secondary students usually bring to Physics classes.

We understand, therefore, that teacher training should go against the naturalization and crystallization of fundamental concepts in physics, in the sense of forming reflexive and critical teachers, open to otherness and diversity of ideas. The teaching of time in the future physics teachers' education must seek dialogue with the historical and cultural narratives of the world. Thus, the different meanings of the concept can be related to mathematics, organisms, situations, and other specific contexts, becoming more familiar to future teachers instead of making sense only in the notes from physics classes. Future teachers must identify other meanings for this concept besides the purely abstract one through a broader repertoire of concrete situations and activities involving time. This ability will allow future physics teachers to introduce discussions about the limits of scientific concepts and their domains of validity in their classes.

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