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Quantum Physics Teaching and the Theory of Social Representations: investigating the presence of Quantum Mysticism concepts among high school students in the south of Brazil[+*]

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Abstract

The present work deals with possibilities for contribution of the Theory of Social Representations (TSR) as a reference for group learning, with techniques and methodologies that are specific to it, to facilitate the teaching of Quantum Physics in High School, allowing to investigate, for example, if students have conceptions linked to Quantum Mysticism. The main objective is to evaluate how this psychosocial theory can be used for the research community in Science Teaching. Our study is majorly based on empirical results from the application of questionnaires in high school (Study 1, N = 291), as well as during the application of a Didactic Activity in a classroom with 34 students (Study 2, N = 34). We proceeded with the construction of similarity networks via a software used in Social Psychology (IRAMuTeQ), networks that are graphic representations of a verbal association test, which may give some indications of what the Social Representation of students looks like. We conclude that the use of TSR is a relevant possibility for the introduction

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of Quantum Physics in High School, and has potential to assist the teacher in the process of establishing scientific literacy, with emphasis on conceptual learning.

Keywords: *Theory of Social Representations; Quantum Physics Teaching; Quantum Mysticism.*

Resumo

O presente trabalho trata das possibilidades de contribuição da Teoria das Representações Sociais (TRS) como referência para aprendizagem de grupo, com técnicas e metodologias que lhe são específicas, para facilitar o ensino de Física Quântica no Ensino Médio, permitindo investigar, por exemplo, se os alunos possuem concepções ligadas ao Misticismo Quântico. O objetivo principal é avaliar como essa teoria psicossocial pode ser utilizada pela comunidade de pesquisa em Ensino de Ciências. Nosso estudo é baseado principalmente em resultados empíricos da aplicação de questionários em Ensino Médio (Estudo 1, N=291), bem como durante a aplicação de uma Atividade Didática em sala de aula com 34 alunos (Estudo 2, N=34). Procedemos com a construção de redes de similaridade por meio de um software utilizado em Psicologia Social (IRAMuTeQ), redes que são representações gráficas de um teste de associação verbal, que podem dar alguns indícios de como é a Representação Social dos alunos. Concluímos que o uso da TRS é uma possibilidade relevante para a introdução da Física Quântica no Ensino Médio e tem potencial para auxiliar o professor no processo de estabelecimento do letramento científico, com ênfase na aprendizagem conceitual.

Palavras-chave: *Teoria das Representações Sociais; Ensino de Física Quântica; Misticismo Quântico*.

I. Introduction

When one uses the expression representation, we have in mind the act of capturing some elements of one entity (real or theoretical) to represent it in another, usually through some symbolic language. In Quantum Mechanics, for example, the different operations in a physical system are implemented by abstract quantities called “operators” or “observables”. Observables are abstract because they operate in Hilbert’s space. As usual observables we have the position operator, linear moment operator, angular moment operator, among others.

When a measurement is taken, for example, choosing the z-axis as the quantization axis, these abstract operators are "represented" by the state vectors of this base. The representation of an operator, on a certain basis, is not unique and there are infinite possible choices. This can be understood through the example of a rotation in our Euclidean space. This symmetry transformation induces, in a similar way, a rotation in the Hilbert space state vectors and consequently implies another direction for the quantization axis.

The phenomenon of representation, then, is common in many areas of knowledge, whit symbols being used as an apparatus of it. If we look to psychology and sociology, in relation to social psychology, we may notice that the use of representations is a common event in the learning process, which was already identified by Jean Piaget, with the Swiss psychologist taking the first step towards an appropriation of the concept. Piaget "studied the representation of the child's world and his investigation remains, to this day, as an example" (MOSCOVICI, 2015, p. 45). In Piaget's theory, representation was a secondary term that was related to the construction of meanings in the cognitive structure of the child. However, in the Theory of Social Representations (TSR) by the Romanian Serge Moscovici (1915-2014), one will find a new meaning and greater importance to the concept of representation.

A current inclination in science education is the concern with the representation of Science established by students in schools. As we may discuss in the present investigation, a common goal in the important field of teaching of Modern Physics is linked to existing misconceptions about Quantum Physics (QP), especially those related to the cultural phenomenon of quantum mysticism, that has different origins (MOURA; SANTOS, 2017; CREASE; MANN, 1982) but in our study was observed when students related *Quantum* to ideas of fiction criticized by some authors (HILGER: MOREIRA, 2012), or ideas spread from self-help books and related topics (PIGOZZO; LIMA; NASCIMENTO, 2019; MOURA; SANTOS, 2017).

Therefore, in the investigation that we present here, we assume that a group of students in the classroom can be analyzed using TSR, due to various manifestations of a social group one may observe in the teaching practice, like conversation that manifest as common thought of the group. In this sense we first analyze the possibilities TSR offers to the professor or researcher in High School contexts, when introducing a new topic, like QP. Subsequentially, in a Didact Activity in classroom, we focused our attention on the introduction of QP, aiming a conceptual learning and the TSR offered fruitful possibilities, showing how this important psychosocial theory can be observed in practice, helping to establish a beginning of science literacy.

II. Theoretical Background

II.1 A brief review on the Theory of Social Representations (TSR)

The TSR is an area of study in Social Psychology which is a branch of Psychology that seeks to study the acquisition of meanings (things, facts, concepts, ideas) by a group of individuals, mixing cognitive aspects of cognitive psychology with concepts of sociology of group collectivity. In cognitive psychology there are many theories that seek to understand how individuals treat knowledge, how they build or acquire it, some of which are the well-known theories of Piaget (1970), Bruner (1977), Ausubel (2003) and Vergnaud (1990). However, the study of how and why individuals share knowledge, creating a common and consensual reality, putting ideas into practice are the objectives of Social Psychology (MOSCOVICI, 2015), which finds echo in the ideas of Vygotsky (2007), when proposing that learning is a process mediated by society and culture. This branch of Social Psychology was further developed by Moscovici, who in the sixties introduced the idea of Social Representation (SR) with the publication of the book "*La Psychanalyse, son image et son Public*" (1961). In our research we used a later work, widely used in Social Psychology research in Brazil, entitled "*Social Representations: Investigations in Social Psychology*" (MOSCOVICI, 2015), which captures the main ideas of the Romanian psychologist.

Moscovici's theory is located halfway between cognitive theories and sociocultural theories, as it understands that the representation, once understood as a mere concept for Piaget, is now understood as a phenomenon, which is not formed neither in the group exclusively, nor in the individual cognitive structure, but in a group that thinks in a common way, generating Social Representations (SRs). Specifically, it is a phenomenon that "becomes social only when it is affected by the behavior of other organisms" (MOSCOVICI, 2015, p. 153). Thus, representation for Piaget assumes an individual character, as an apparatus in the cognitive structure for the construction of a mental model on a given subject. For Moscovici, however, this construction is social, it may reflect the individuality of the group's components, but with certain aspects and meanings that arise only when the group interacts. This interaction takes place through conversation. With that in mind, Moscovici elaborates a definition of Social Representation as:

> *a system of values, ideas, and practices, with a double function: first, to establish an order that will enable people to orient themselves in their material and social world [...]; and second, to make communication possible between members of a community, by providing them with a code to name and classify, unambiguously, the various aspects of their world and their individual and social history* (MOSCOVICI, 2015, p. 21).

In addition to this relationship with Piaget's theory, as already mentioned, there is an inherent influence of Durkheim's social theory on TSR. In fact, Moscovici emphasizes that "it is obvious that the concept of social representations came to us from Durkheim"

(MOSCOVICI, 2015, p. 45). Durkheim used in his social theory, mainly in "*The Elementary Forms of the Religious Life*" (1912), representation as something inherent in society; something fixed for a given group of people, assuming then, the form of *collective representations*, which are explanatory instruments, related to different ideas and beliefs. However, in TSR, representations are understood as specific phenomena that "are related to a particular way of understanding and communicating" (MOSCOVICI, 2015, p. 49), in a way that a change in the form of communication, or absence of it, substantially modifies the representation. Because of that, communication and its analyses are substantially important for the methodology of any study on TSR.

Withal, the representation is understood by Moscovici as something dynamic, it changes with time, leaving the static nature established by Durkheim. To emphasize this distinction, he uses the term social, rather than collective. Therefore, while in Durkheim's theory the *collective representations* are taken as stable forms of collective understanding, with the power to compel, and which can be used to integrate society, TSR looks at the variation and diversity of collective ideas in society. Moscovici also warns that the concept of *collective representation* is expressed through "the notion of the collective style of thought used by Fleck. And we know that Fleck's ideas found an echo on Thomas Kuhn's theory and in his epistemology of science" (MOSCOVICI, 2015, p. 194), something that is already well elucidated in studies about the epistemology of Thomas Kuhn and Ludwik Fleck (MASSONI; MOREIRA, 2015).

Therefore, any representation appears in the group in interaction, since "people and social groups create representations in the course of communication and operation. Representations, obviously, are not created by an individual in isolation" (MOSCOVICI, 2015, p. 41). Once created in the group, they take on a life of their own, circulating and manifesting themselves in different situations, they can change, generate new representations and eventually disappear, giving space to other representations. However, both the appearance of a new representation, and the modification of an old one, requires communication between individuals. SRs are like a *collective common sense*, a type of simplified information with more intricate and shared concepts, a reality to which the mass media, science, religion and even the interaction between social groups contribute.

When the object of analysis of the TSR is a social group, for example when one aims to modify the thinking of a group towards a given topic or concept, like Quantum Physics, it is necessary to have access to that previous thought. Moscovici clarifies: the thought of a group is the speech and, quoting the Franco-Romanian poet Tristan Tzara, he states: "We think through our mouths" (MOSCOVICI, 2015, p. 42). Consequently, the most important way that social psychology has to access the formation of new ideas and values in the group is through communication and its analysis. To deny that a society thinks, would be to retake the idea that "our minds are small black boxes, inside a larger black box, that simply receives

information" (MOSCOVICI, 2015, p. 44), what would bring psychology closer to the outdated classical behaviorism.

In this way, to identify a SR, the starting point is the analysis of conversation practices in a group. It is worth mentioning that the identification of a SR demonstrates inherent contradictions, originated from Durkheim's sociology, which means that they are rigid/static enough to establish a value system, but they are at the same time constantly changing. To deal with this apparent dichotomy, it is understood that an SR actually has two parts. One is marked by collective memory, values, and historical conditions. This set is rigid and is not subject to the immediate material and social context, forming the so-called Central Nucleus (or central core) of a SR; the other, forms the so-called Peripheral System of a SR, for which the immediate material and social contexts have a strong influence.

The nucleus and the peripheral system are indirectly addressed in Moscovici's work, but they are not explicitly mentioned. The elucidation of these terms, as highlighted by Maturano and Mazzitelli (2017), Hilger and Moreira (2012) and Sierra (2011), is a contribution from another social psychologists, who continued and expanded Moscovici's work, the French psychologist Jean-Claude Abric (1914-2012), who writes that:

> *It is the existence of this double system that allows one to understand one of the essential characteristics of social representation that could seem contradictory: they are sometimes stable and mobile, rigid, and flexible. Stable and rigid because they are determined by a central core deeply anchored in the value system shared by the members of the group; mobile and flexible because they are fed by individual experiences and integrate the specific experience and situation, the evolution of relationships and social practices in which individuals or groups are inserted* (ABRIC, 2001, p. 27).

The notion that a SR has a nucleus and periphery, as represented in Figure 1, is extremely useful because of the possibility it offers to visualize a representation of a group in a clearer and more detailed way, even if just theoretically. In this sense, Moscovici emphasizes that representations are "almost tangible entities" (MOSCOVICI, 2015, p. 10). When it is possible, for those using the TSR, to identify the nucleus and periphery, then, in a better way, the representation assumes this almost tangible nature.

Moscovici emphasizes that representations circulate and crystallize continuously through a word, gesture, or meeting, in our everyday world. Thus, it could be inferred that a representation may emerge for a given subject in Physics, for example, related to words such as "Quantum" or "Plasmas". Expressions or words, as Moscovici says, that students relate more directly to these terms will be related to the central core; are more rooted ideas and, therefore, more difficult to modify (if a modification is necessary). Furthermore, when there is a substantial change in the nucleus, Moscovici indicates that the old representation is abandoned, and a new representation is formed. In the context of the classroom, for example, when introducing a completely new object of study, like quantum physics for example, it is

most appropriate to understand that a new representation arises. When approaching an already well-known subject, it is understood that there is a change in the old representation. Evidently, the creation of a SR is not an immediate or instantaneous process, on the contrary, Hilger and Moreira (2012) emphasize that this is a process that takes time, since students need to appropriate new concepts, even so, when a new content is given, the process of formation of a new SR has started. After, for example, a month of an introduction of Quantum Physics (as it happened in our Study 2), we understand that enough time has passed for students to acquire (or build) new knowledge about concepts they did not know (introductory quantum concepts), so it is reasonable to assume that a new SR is formed, which can evolve and change as classes continue, where students may have the possibility to communicate and to discuss the topic, in order to constantly remodel the group's SR.

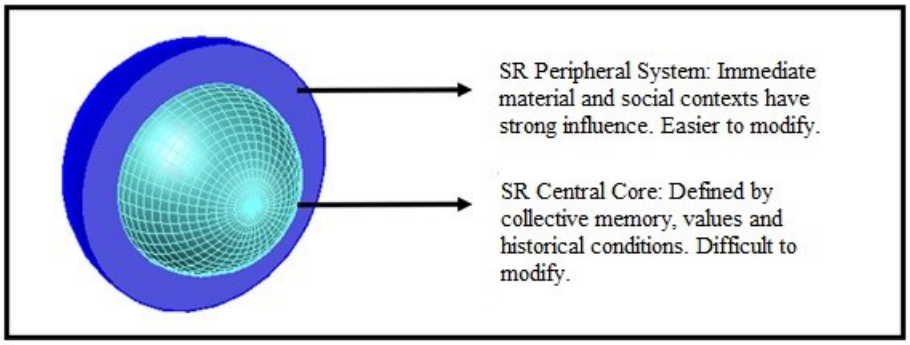

Fig. 1 – A brief representation on the two aspects of a SR: the core and the periphery. Elaborated by the first author, 2020.

About the social place where the representations emerged, Moscovici emphasizes that there are two universes, the consensual and reified universes, which replace the notions of sacred and profane sciences from previous theories from Sociology of Science. He points out that "it is easy to see that sciences are the means by which we understand the reified universe" (MOSCOVICI, 2015, p. 52). The reified universe presents itself as the whole set of well-established representations, comprising everything that is taken or understood as a scientific fact. This universe is not subject to the context or to the individualities of the group, identity is not considered. On the other hand, the consensual universe comprises knowledge that is modified over time by social groups, transforming the different topics of the reified universe in terms and language accessible to the group, forming a consensual universe with the use of SRs. In this way, Moscovici argues that the TSR allows an analysis and understanding of the formation of consensual universes, often distant from the reified universe. An example would be quantum mysticism, compared to quantum physics. Given that SRs in the consensual universe distance themselves from the reified universe, Moscovici emphasizes that, in society, "the purpose of all representations is to make something unfamiliar, familiar, or the unfamiliarity itself" (MOSCOVICI, 2015, p. 54).

Moscovici warns that it is not always simple to transform unfamiliar terms, ideas, or beings, into usual and current words, which can be seen as one of the many challenges for teachers in the introduction of any new content. In order to be familiar, it is necessary to put into operation the two basic processes that generate a SR: *anchoring* and *objectification*. First, anchoring is a mechanism that transforms new ideas, that can be strange or disturbing, in more familiar terms. For example, "a religious person tries to relate a new theory, or the behavior of a stranger, to a religious scale of values" (MOSCOVICI, 2015, p. 60). Summarizing, anchoring is to classify and to name something. Something that cannot be classified and cannot be made familiar essentially does not exist for the group. On the other hand, objectification is the mechanism that deals with the formation of images by the group, transforming something that was previously abstract into something concrete. The objectification of the divine figure is an example, where religious people compare "God with a father and what was invisible, instantly becomes visible [...], as a person to whom we can respond as such" (MOSCOVICI, 2015, p. 72). Some concepts do not allow direct image formations. Quantum Physics is full of these concepts, so the images blend together forming what Moscovici calls the figurative core, which is a set of images, or "a complex of images that visibly reproduce a complex of ideas" (MOSCOVICI, 2015, p. 72). With objectification, "the image of a concept ceases to be a sign and becomes a replica of reality" (MOSCOVICI, 2015, p. 74), where there is the conventionalization of reality. And we know, from Bachelard (1947), that the exaggerated formation of images in an area such as Quantum Physics is complicated, since we are dealing with mathematical entities and the whole idea of observation has a different interpretation; but Moscovici warns that the formation of images, even in the form of a figurative core, always occurs when a new SR emerges. Those ideas of anchoring and objectification are summarized on Fig. 2.

Figure 2, therefore, shows a simplified scheme of the process and consequences of the formation of a SR. The figure is read clockwise from the top. The importance of discourse for the formation of a new SR is highlighted, with the symbolic material being understood as the key concepts present in the formation of a representation, the anchoring and the objectification.

II.2 A brief overview on the phenomenon of Quantum Mysticism

When using the TSR to identify the conceptions of a group of students about Quantum Physics (QP), one may find out that in the SR of the group there are ideas, in the peripheral region or in the central core, related to what may be understood as quantum mysticism, as it happened in our research (HOERNIG, 2020). Even though the focus was to understand TSR, and how this theory can be used in teaching practices, the phenomenon of Quantum Mysticism is a complex subject, and one must take some cautions on demarcating what is mystic in students' conceptions and what is not. There are recent works focused on this topic, (SAITO, 2019; PIGOZZO; LIMA; NASCIMENTO, 2019; MOURA; SANTOS,

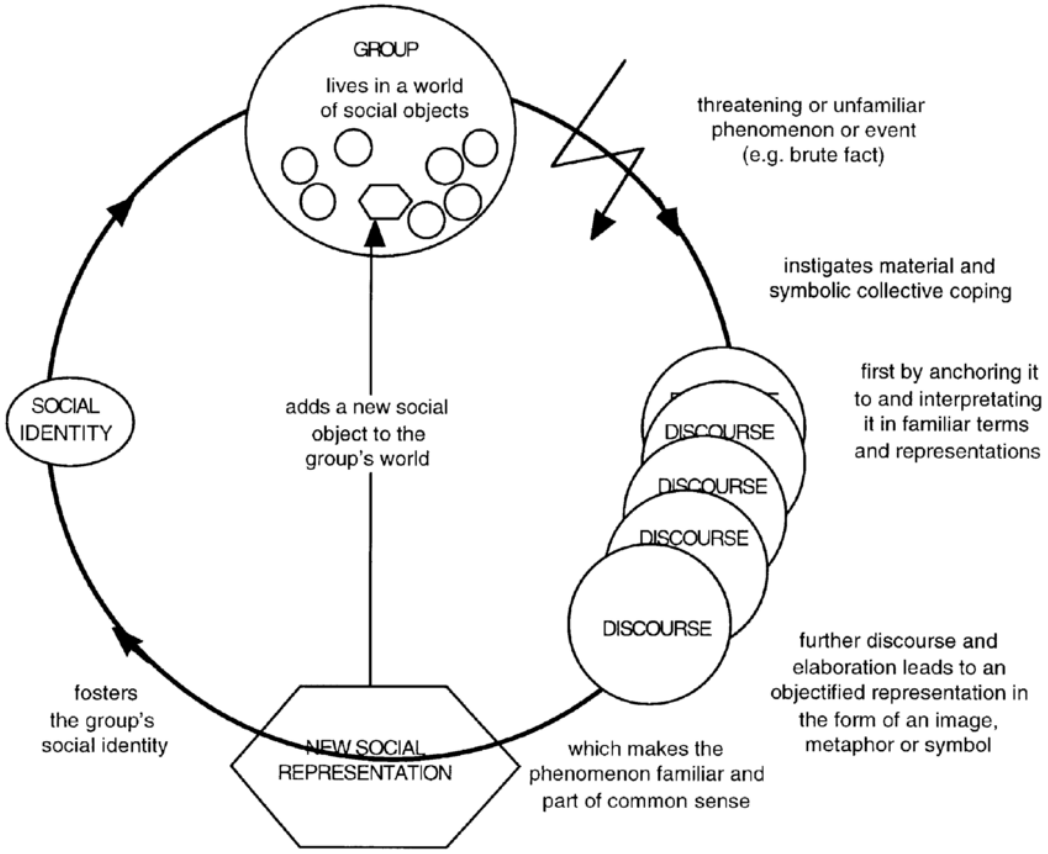

Fig. 2 – A diagram that illustrates the process of acquiring knowledge, in the formation of new SR, according to the TRS. Wagner et al. (1999).

2017), and here we take some more general precautions, without, for instance, dwelling on discussions about Foundations of QP. An initial delimitation of what constitutes quantum mysticism is made by Pigozzo, Lima and Nascimento (2019), when stating that philosophies that interpret Quantum Physics from an idealistic or even spiritualist point of view are called quantum mysticism. This is in consonance with Freire Jr, Pessoa Jr and Bromberg (2011):

> *"Quantum mysticism", in general terms, consists of interpretations of Quantum Theory that are part of the tradition of animistic naturalism (with its transformative idealism) or that adopt a subjectivist idealism, or even that emerge from religious elements. It is an attitude that attributes an intimate connection between human consciousness (or spirituality) and quantum phenomena* (FREIRE JR; PESSOA JR; BROMBERG, 2011, p. 286).

Crease and Mann (1982) discuss how the mystic conceptions arose from the philosophical difficulties that came with the birth of Quantum Mechanics, especially from the Copenhagen interpretation "anchored on the – perhaps (at least for some) mystifying concept of complementarity" (BALSAS; VIDEIRA, 2013). Thenceforward, many interpretations from Quantum Mechanics were extrapolate to various ordinary situations, like "the observer creates

reality", "free will is guaranteed by the uncertainty principle", among others (MOURA; SANTOS, 2017), situations that had influence, for example, in many situations in literature and also cinema industry. In this sense, Hilger and Moreira (2012) discuss the influence of the media and identified possible SRs of students about quantum theory. The authors identified that some ideas that may be linked to quantum mysticism can often play a central role in the students' SR, and this is mainly due to external influences other than the context of the classroom. They point out that, when students were asked what "Quantum Physics" reminded them of, many answered:

> *words that appeared in texts, books, newspapers / magazines about quantum physics, such as thought, water, attraction, mind, brain, feelings, dimension, vibration and so on. Strangely, the term "water" is at the core of representations of 1st and 2nd year students [...] and is also related to quantum physics in the movie "What the bleep do we know?"* (HILGER; MOREIRA, 2012, p. 59).

The authors point out that any topic that constantly inspires movies or discussions in the public context, as is the case of Modern Physics, will end up, in some level, receiving a distorted image, forming the so-called consensual universe about the theme. All knowledge built in this universe has no defined rules or any clear objective, but it has its own logic, which would make something unfamiliar into something familiar, in this case, making QP familiar, what causes misconceptions and conflicts whit scientific knowledge. Similarly, Moura and Santos (2017), when analyzing many books from Brazilian bookstores, observed that books that could be classified as "mystical" almost always had the following words (repeated several times): spirituality, mind, help, love, Indian, humanity, practice, objectives, wisdom, cure, diseases, spirit, sects, problem, justice, Menezes (this is due to a Brazilian author who writes about self-help), singular, renown, ethics, functioning, concise and beliefs. In fact, they state that "it is difficult to imagine words such as 'spirituality', 'love', 'healing' and 'spirit' as being part of a scientific text on quantum mechanics, being, however, quite compatible with the 'theses' of the quantum mysticism" (MOURA; SANTOS, 2017, p. 15). From a methodological point of view, this is important when defining conceptions of students, if these conceptions are related to quantum mysticism (consensual universe for TSR) or not. For simplification, we stablished ourselves in a similar attitude as Moura and Santos (2017) and Hilger and Moreira (2012) when deciding what expressions and words answered by students could be classified as mystical or not, as explained in greater detail in Hoernig, Massoni and Hadjimichef (2021).

III. Methodology

III.1 Application in High School: Study 1

The literature in the area shows that researches covering TSR are multi-methodological (SOUZA; WALL; THULER; LOWEN; PERES, 2018; LO MONACO; PIERMATTÉO; RATEAU; TAVANI, 2017; MATURANO; MAZZITELLI 2017; MORALES; MAZZITELLI; OLIVERA, 2015; DANY; URDAPILLETA; LO MONACO, 2014; HILGER; MOREIRA, 2012), with instruments and techniques not always being standardized. In our research activity we used some ideas from other works that used TSR regarding verbal association (or word association technique), so we could have an image that resembles the structure of a Social Representation – SR (core and periphery).

Attempting to identify the SR of a sample of high school students about Quantum Physics, we conducted a survey through free evocations (words, lexemes), to be able to carry out an analysis of associations between these evocations. In this sense, we rely, for example, on the work of Daniel Kahneman (2012), which addresses that the words evoked in this type of test are related to each other, in what he calls *priming effect*. From the evoked words, one can have indications of the SR structure. Terms most frequently evoked can be understood as somewhat related to the central core, whereas less evoked terms can be related to the periphery of the SR. It is important to emphasize that these are only indications, as there is still no evidence in Social Psychology to affirm that evoked words certainly form core or periphery of a SR. This word evocation activity is known as the Free Word Association Technique – FWAT, which is one of the most important methodologies for structural approach to representations, having been elaborated by researchers in Social Psychology in France (DI GIACOMANO, 1981). To obtain these evocations, we conducted a short questionnaire that was applied in the years of 2018 (Study 1) and 2019 (Study 2). It was applied personally by the first author in three schools (as detailed below), and was delivered to students manually, with the questions printed on half a sheet of paper. It is important to notice that there are many possibilities to the elaboration and application of this type of questionnaire. Our delimitations were that the questionnaire should be as simple as possible and the students could freely talk between then, so the evoked terms could be more representative of the whole group[2]. We detail more this process in the current section. The questionnaire contained the following main question:

• *"Write all the words or expressions that come to your mind when you hear the word 'Quantum'".*

[2] Terms of Commitment with permissions from students, or parents, to gather and use the information given were collected whenever possible. We do not replicate the Terms here, but they are entirely available in Hoernig (2020).

We clarify that we chose not to use "Quantum Physics" in the question because we believed that the term "Physics" could limit the evocations of students, who could provide lexemes that were directed linked to the discipline. We aimed to give students more freedom, clarifying that the questionnaire had no connection with the classes of any teacher in the school, being a survey done by someone outside the school.

Therefore, this short questionnaire was applied in two different situations, Study 1 and Study 2. Study 1 was conducted in 2018 in order to have a general investigation of several schools; 291 students from three state public schools participated (two schools in the city of Porto Alegre – Flores da Cunha Education Institute and Rio Branco State Institute – and one school in the city of Gravataí – Heitor Villa-Lobos School). Subsequently, in Study 2 we reapplied the questionnaire in the school at Gravataí, at the beginning of a Didactic Activity with a class of 34 students, in order to study how a SR would be influenced by our lessons. The Didact Activity (or Didact Module as we called) was partially one objective of the Master's Degree of the first author, since we wanted to evaluate how our research would manifest on practice, not just on theory. After the classes were conducted, we reapplied the questionnaire with these students to identify whether there was any indication that the SR of the students was modified due to our intervention, and to what extent it could have been modified.

To have indications on the SR, we proceeded with an analysis of similarity for the construction of a semantic network, whose structure resembles the core and peripheral regions of a SR. An analysis of this type can be done with a graph, or network, in which an evoked lexeme appears at each vertex and at each edge a similarity relationship between two lexemes. The thickness of the edges, in the graph presented in the section "Results and Discussion", is proportional to the measure of similarity between two connected terms. These graphs are called networks of similarity, since they allow the visualization of the similarity between evoked terms. The construction of these networks can be done with different free softwares for qualitative analyses, and:

> *One of these free software programs is IRAMUTEQ (Interface de R pour les Analyses Multidimensionnelles de Textes et de Questionnaires) created by Pierre Ratinaud, and until 2009 it was only available in the French language; however, it currently has complete dictionaries in several languages. IRAMUTEQ is developed in the Python language and uses functionalities provided by the statistical software R. It began to be used in Brazil in 2013 in social representation studies, although other areas have also been using it and contribute to the dissemination of the various possibilities of qualitative data processing, since it allows different forms of statistical analysis of texts produced from interviews and documents, among others. Descending Hierarchical Classification (DHC) is one of the analyses performed by IRAMUTEQ software and has already been proposed by the software ALCESTE (Analyse Lexicale para Context d'un Ensemble de Segments de Texte). In addition to DHC, IRAMUTEQ includes other forms of analysis such as classic textual analyses,*

> *analyses of specificities, similarity analysis and a word cloud.* (SOUZA; WALL; THULER; LOWEN; PERES, 2018, p. 2).

We choose then the IRAMuTeQ software to conduct our research, specifically to perform analyses of similarity (or similitude). The software automatically performs the similitude analysis after the data is properly prepared, allowing the user to build similarity networks. On the website of the software[3] one may find detailed instructions with accessible language about how to properly prepare the data.

III.2 Application in High School: Study 2

After the execution of Study 1, we desired to introduce Quantum Physics in High School (HOERNIG; MASSONI; HADJIMICHEF, 2021), since, although the introduction of Modern Physics by the research community in Physics Teaching and by Brazilian public educational documents is encouraged, in the Brazilian context Quantum Physics does not reach, in fact, the vast majority of schools (HOERNIG, 2020) or schools in the context of Latin America in general (CUESTA-BELTRÁN, 2018).

With authorization from the school's management and the school's Physics teacher (who had a graduation in Mathematics, but not in Physics), we conducted the Study 2 at the Heitor Villa-Lobos School, in Gravataí. This college had also been present in our Study 1. In fact, there was a desire to conduct Study 2 in one of the three schools where Study 1 had been conducted, in order to assess how similarity networks changed from 2018 to 2019, to study SRs.

Thus, the same short questionnaire used in Study 1 was reapplied in Study 2, on the first day of contact with students, and then at the end of our Didactic Activity (after, approximately two months with those 34 students, with two encounters per week – approximately 50 min each), in the weekly periods given to us by the teacher at the school. To better substantiate our data obtained via the verbal association questionnaire, we recorded all the classes that were given, and to do that, we gave to students a term of commitment. The classes were all recorded and also transcribed (HOERNIG, 2020). In addition, at the end of each class, with a logbook, each important consideration was noted, in case the recording failed. In this way, we took note of each important speech of the students that could be related to some important aspect of TSR. This is in line with what Moscovici points out, that the main methodological resource associated with TSR is "to obtain material from samples of *conversations* normally used in society" (MOSCOVICI, 2015, p. 89, *emphasis added*). Given the importance so often emphasized of the conversation in the TSR, the importance of this methodological principle is clear. Moscovici (2015) also emphasizes that environments where individuals feel more comfortable, such as lounges or cafes, are the most propitious to observe the emergence of new meanings, which may result in anchoring. For this reason, we

[3] Available at: <http://www.iramuteq.org/>, visited on February 3, 2023.

defend that the classroom is a place where TSR can be used more easily in some contexts, since students may come from adverse and complex economic and social situations, so the classroom usually becomes the only place where students have some peace, in some situations, it becomes even the only place where students have something good to eat. In fact, in our context, we observed that the chosen school was located close to the region known as "Morro do Coco", a region affected by drug trafficking, so the school was a place where students felt comfortable. Accordingly, Leite *et al.* (2016), for example, conducting a study in an area of social vulnerability in the northeast of Brazil:

> *As for school, teens recognize it as a place of knowledge and learning, which enables the prospect of a decent future through qualifying, but the identified direction is the school as a privileged space for the encounter with the other, for cultivation affective ties, to exchange, for dialogue, cooperation and fun* (LEITE *et al*., 2016, p. 1).

The Didactic Activity on Quantum Physics took place during the months of September and October 2019, with the short questionnaire being applied in the first class of September and the second application of the questionnaire in November 2019. We did not apply the questionnaire immediately after the end of the classes, because we wanted to evaluate whether students would still remember concepts and if they would make good associations and then, we would have better indications if the evoked terms really could be related to core or peripheral regions of a SR.

III.3 Methodological limitations of this study and researches on SR

It is important to note that all researches on TSR may have some limitations, as highlighted by Lo Monaco, Piermattéo, Rateau and Tavani (2017). The authors point out that a research using the technique of verbal association, as we do, may face a dilemma between reliability and viability. It is important to apply a word association questionnaire in a simple and direct way, simplifying students' work so they can bring the best possible answer to the evocation test (that may or not be correct under the scientific point of view). And this "identification of the content is a fundamental step and *sine qua non* for all SR studies" (LO MONACO; PIERMATTÉO; RATEAU; TAVANI, 2017, p. 6). But there is a limitation in these questionnaires: for the student to feel more comfortable and answer everything that comes to mind, the questionnaire should be anonymous. If the student is asked to write the name, then if he/she associates "quantum" with some term that considers wrong, he/she will not want the re-searcher or colleagues to think that he/she does not know anything about what is being asked. The questionnaire being anonymous can resolve this issue, making the student more comfortable and freer to answer more terms. But if we do not know the student's name, it is practically impossible to conduct interviews to find out what the students meant with some expression or word that the researcher may consider ambiguous or confusing. In

addition, our Study 1 was conducted with a relatively large number of students (N = 291), applying interviews could be almost infeasible due to the number of students.

There are two possible answers to this type of situation. The first is that with this research we do not want to bring a definitive study or treatise on Social Representations, we are not social psychologists. *Our goal is to provide a tool that can help science teachers or researchers in the field to get a sense of the students' SR before conducting their classes*, to identify, for example, if there are notions related to quantum mysticism, or any topic that comes to students' minds about a topic, so the teacher can better prepare the classes and have some indications about the SR of the group. It is evident that *a simple word association test will not bring out the ready and definitive SR of the group of students*. A SR does not even exist physically, it is a construct of social psychology that can be applied to teaching practices.

The other answer to this limitation is in didactic practice itself. In order to find out if terms evoked can really be related to the central core of a SR or to the peripherical region, *the collection of students' speeches during the application of the questionnaire and during classes can assist the researcher*. Perhaps it is important, as we did, to encourage students to talk to each other during the questionnaire, so the evoked terms, along with the analysis of these conversations, can reveal whether we are dealing with consensual terms common to the group or not.

Lo Monaco, Piermattéo, Rateau and Tavani (2017) also highlight that it is a common problem in these approaches, that researchers may group terms answered by individuals, in the sense that similar terms can be grouped with their semantic proximity, despite their greater or minors morphological differences. For instance, different individuals may answer "alcoholic", "alcoholism" and "alcohol", and for simplicity, researchers could group all these responses into a single category called "alcohol". This may be necessary sometimes, and for the researcher these words may be similar, but for a computer they are completely different. Even words that differ only by being in the singular or plural are understood as different for a software, so the researcher needs to make these adjustments carefully. The limitation is related to the fact that it is not possible to measure what the student was really thinking when he/she wrote a certain word, in the sense that an individual who answers "alcohol" may be thinking about an alcoholic drink, or alcohol gel to sanitize hands; the researcher has no way of finding this out if the questionnaire collected is anonymous, since the researcher will not be able to conduct an interview with the student. In our research, fortunately the words did not show double meanings (in our interpretation) and the set of words were made only in singular and plural, therefore without loss of meaning. Thus, similarity networks were constructed as much as possible with the words evoked by the students, without major modifications that could result in loss of meanings. Words that could be confusing or senseless were studied based on our theoretical framework, revealing at times, terms associated with mysticism or spirituality, which will be discussed and analyzed in the next sections.

IV. Results and Discussion

IV.1 Study 1

In the initial application (in 2018), 291 students from the three selected schools answered the questionnaire. Our sample for this first study counted 100 students from the Flores da Cunha Education Institute, in Porto Alegre, 97 from Rio Branco State Institute, in Porto Alegre, and 94 from Heitor Villa-Lobos school, in the city of Gravataí. For evocations linked to the term "Quantum", we obtained 701 words or short expressions (evocations). All these terms were transcribed and later analyzed with the program IRAMuTeQ.

However, it was necessary to separate these students into characteristic social groups. The TSR indicates that a SR is seen as a phenomenon to which a particular way of understanding and communicating is related (MOSCOVICI, 2015), therefore, a SR is something typical of a particular group of individuals. Taking three groups of students from three different schools located in different locations and even different cities and trying to analyze a single SR for all 291 students was understood as something to be avoided, since the 291 students were not a homogeneous group; they had local peculiarities and contextual specificities. The students from the different schools that made up our sample certainly do not all interact with each other (and here we use the most ordinary sense of the term, that students do not meet and talk every day, it is not the broader sense of conversation or communication in the scope of society) in such a way that the characteristics of the group would be lost, which form or shape SR, such as, for example, the conventionalization of a SR.

The most appropriate, possibly, would be to assemble evocations for each class individually so, with the help of the software, we would be able to build a similarity network that would allow analysis of the SR of each small group. However, if we did so, we would be facing many networks of similarities, which would take an excessive amount of time to analyze. Thus, we divided, at first, the evocations obtained by school, assuming that students from different classes in the same school had a minimum interaction in environments outside the classroom, such as in the courtyard or in the cafeteria, for example. At this point, in consonance with Moscovici (2015), since he emphasizes that places where individuals feel more comfortable are more suitable to observe the emergence of new meanings, which may result in anchoring of new concepts in a SR. In this way, according to the TSR, we understand that it is reasonable to take the respondent students from a school and assume that they share their own SR, with a certain uniformity; on the other hand, it does not seem appropriate to formulate a single similarity network for all 291 students who answered the questionnaire.

In this way, we built three networks of similarity, one for the 100 students of the Flores da Cunha Education Institute, with 303 evocations; one for the 97 students at the Rio Branco State Institute, with 216 evocations, and another for the 94 students of the Heitor Villa-Lobos School, with 182 evocations. Each group of evocations was then transcribed and prepared by the researcher to then analyze with IRAMuTeQ. In this section, we present only the network for Flores da Cunha Education Institute, the others are not shown here because

they showed similar results and we did not want to extend the article, but they can be seen in Hoernig (2020). The software allows the user to select the formation of clusters in different colors, and these clusters are automatically created by the software based on similarities of responses (not semantic similarities, but similarities in the pattern of the students' responses). Therefore, another option would be to build a similarity network without clusters, it would be a network that only shows the relationships between words; we opted for the formation of clusters. Those clusters do not change the similarity network, they serve only to the purpose of better visualization of the data. In this way we obtained the similarity network shown in Fig. 3.

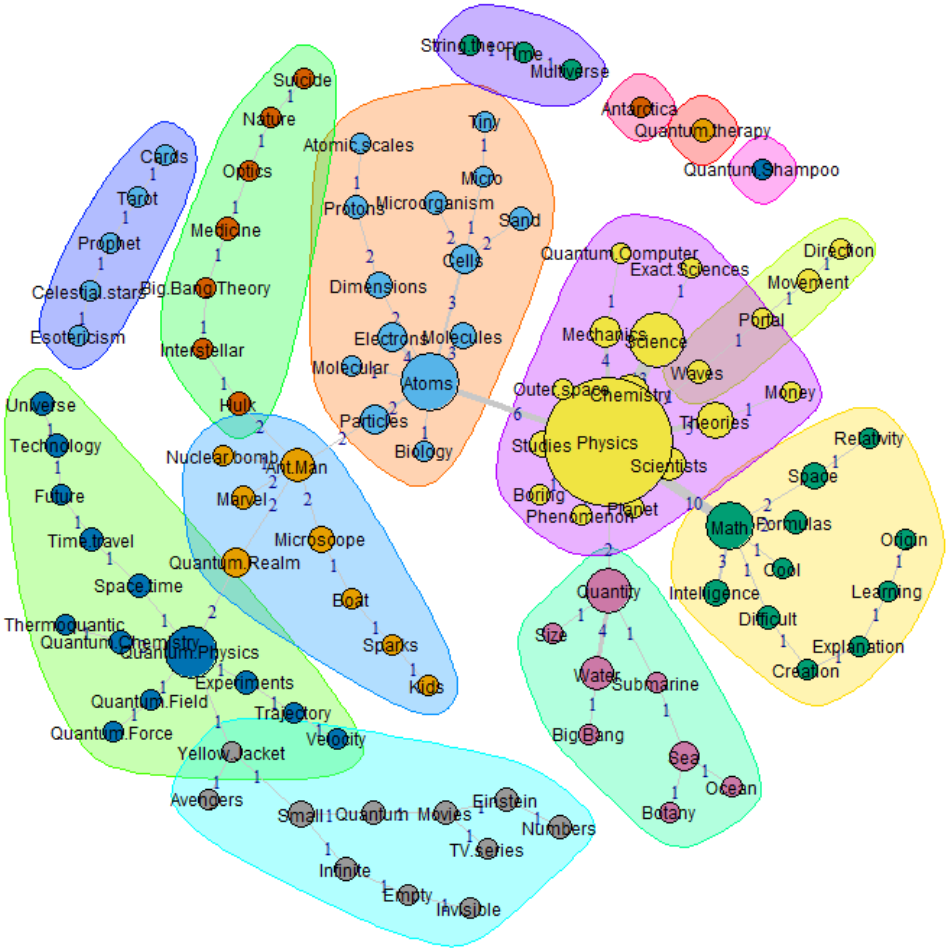

Fig. 3 – Similitude Network based on evocations obtained at the Flores da Cunha Education Institute, in Porto Alegre (N = 100). Elaborated by the first author, 2021.

In this way, a network of similarities (or similitude network) between evoked terms has been created, based on the use of FWAT, which offers a simplified preview of the SR for this group of students. We emphasize that *the similarity network is not the SR itself*, but can be understood only as a graphical representation of elements that make up the SR. The central

region is automatically formed by the program based on, essentially, the word that has appeared the most was “Physics”, which was remembered 38 times.

It is worth mentioning that the topics usually listed in curricula for the Teaching of Quantum Physics (KRIJTENBURG-LEWERISSA; POL; BRINKMAN; VAN JOOLINGEN, 2019), such as Uncertainty, Probability, Duality and others (HILGER; MOREIRA, 2012), which constitute the reified universe of the topic (MOSCOVICI, 2015) are not observed in this network of similarities, therefore, it is possible to state that these scientific terms are not present in the SR of this group. We interpret this as a possible manifestation of the systems of thought highlighted in the work of Kahneman (2012), System 1, fast and intuitive, and System 2, slow and reflective. Kahneman (2012) points out that System 1 is the one that operates automatically, without effort and perception of voluntary control, working quickly and being responsible for intuitive thinking. When a student is asked to answer what comes to mind when hearing or reading the word “Quantum”, the answers will generally be intuitive, without much thought or effort, and therefore these concepts emerge under the influence of System 1, which in many cases it is disassociated from the reified universe (MOSCOVICI, 2015) for Quantum Physics. In other words, quite possibly, this observed intuitiveness tends to show that the reified universe, related to scientific literacy, had not arrived at this school, allowing the emergence of different participation roles, anchored much more in individual experiences.

In the similitude analysis represented in Figure 3, based on the evocations of students from the Flores da Cunha Education Institute, each evoked expression is highlighted in the network by a circle, which increases for each new evocation, which means that each time a term receives a new mention, the circle corresponding to that term increases. On the other hand, each edge that joins two lexemes indicates the relationship between two evoked lexemes. For example, among the thirty-eight students who mentioned “Physics”, six of them also mentioned “atoms” (eleven times); among the eleven students who mentioned “atoms”, four also mentioned “electrons” (five times), and so on, for each edge that joins two lexemes.

The central cluster in purple with evocations in yellow contains some terms that can be understood as related to the central core of the students’ SR, which contains the most remembered expressions, or expressions directly linked to them, as is the case of “boring” and “math”, for example, which are in this network directly related to the term “Physics”. According to the Moscovici TSR and later works in Social Psychology (ABRIC, 2001), it is understood that the central core of a SR is the most stable sector of the representation, so it resists more to changes, since what constitutes the nucleus is anchored in the value system shared by group members.

For this similarity network in Figure 3 there are no conceptions linked to quantum mysticism that are directly associated with the central region, but they are in the peripheral region of the similarity network, and if we interpret this as linked to the periphery of the SR, then they are terms that are in a region considered more flexible, which, being fed by

individual experiences (ABRIC, 2001), does not constitute homogeneity in the group and, therefore, quantum mysticism does not constitute a common thought to this group. According to Abric (2001), ideas that are identified as peripheral are transitory, subject to immediate contexts and conditions and do not reflect a stable and homogeneous common thought of this group.

By identifying that those expressions related to quantum mysticism are not widely remembered by students and, therefore, are not consensual to the group, it is possible to indicate that these expressions most likely do not form the central nucleus of SR. In this sense, there is, for example, the formation of the cluster highlighted in dark blue in the upper left part, which contains the expressions "tarot", "esotericism", "celestial stars", "prophets" and "letters"; the orange cluster containing the lexeme "Quantum Therapy" and the purple cluster containing the term "Quantum Shampoo". Each of these clusters corresponds to only one student each, with these evocations not reappearing for any other student. In this sense, they may be understood as forming the periphery of the SR, in accordance with what was pointed out by Abric (2001), that they correspond to individual experiences and specific situations. As they constitute the periphery of SR, they are lexemes that correspond to ideas that may change more easily and eventually be replaced by concepts more appropriate to Quantum Physics, more articulated to the scientific consensual universe (HILGER; MOREIRA, 2012), or scientific reified universe (MATURANO; MAZZITELLI, 2017), or simply reified universe, as highlighted by Moscovici (2015). If expressions somewhat linked to mysticism were identified as belonging to the central core (if they had appeared many times or strongly linked to very remembered expressions) the situation would be of greater concern, and a more careful work should be conducted in a possible didactic activity.

It is also observed in this network of Figure 3 the word "water" (six times), close to "sea" (three times) and "ocean" (one time). These words seem to have little or no relation to "Quantum", however, as identified by Hilger and Moreira (2012), these expressions and others such as "thought" and "mind", are commonly related to Quantum Physics due to misconceptions on the subject, commonly disseminated in science fiction movies, or in cartoons and children's stories as pointed out by Vílchez-González and Palacios (2006).

However, unlike Hilger and Moreira (2012), we did not identify those terms as truly relevant in the similarity network (they did appear many times and, when they appear, is only in the periphery), and therefore, do not represent rotted ideas for this group. Another cluster that shows relevant characteristics is highlighted in light blue and also light green in the lower left part of the network, which also contains terms related to science fiction and cinema in general, since it contains lexemes such as "Ant Man" (Six evocations), "Marvel" (two evocations), "Hulk" (two evocations), among other, directly related to fictional characters, who tend to be captivating among this younger audience, especially with large movie productions that recently approached the idea of time travel through what is called the quantum realm. This cluster, when identified, can be taken as something useful for the

Teaching of Physics, and, as Park, Yang and Song (2019) warn, the relevance of Modern Physics and NOS (Nature of Science) aspects can be maximized when the teacher or textbooks make the connection between the content studied is school and fiction movies, making the teaching activity more relevant and interesting for students.

This constitutes a first contribution of the analysis with FWAT for the Physics Teaching research, that is, the ability to guide the didactic activity based on what the group thinks and knows about a certain subject, which has relations with the group's SR. Our Didactic Activity was conducted in the year following the application of this questionnaire, in a class at the Heitor Villa-Lobos school, we were able to assume that a large intervention was not necessary to mitigate conceptions about quantum mysticism, since these terms related to mysticism are weak (as better explained in the next section), so only some comments and quick considerations were necessary. We now bring some considerations of our didact activity and how we used the TSR in the classroom.

IV.2 Study 2

In a second part of our research, we started the Didactic Activity with a reapplication of the same questionnaire that had been applied the previous year. In this way, we carried out a new initial survey to visualize how the network of similarities of this group was constituted before the application of the Activity, in order to have indications of the SR of this group. This new application is relevant to our study, since we aimed to investigate how a SR on Quantum Physics changes, so a new questionnaire with FWAT was applied at the end of the Activity, allowing a comparison of the similarity network before and after classes.

In this way, we conducted analyses with a similarity network at the beginning of the Activity, now with evocations only from the students that participated in the Activity. Thirty students were present in the classroom when the questionnaire was applied. With their responses, we obtained a total of sixty-five evocations, which make up the network of similarity shown in Figure 4.

Hear we have a network with fewer expressions and fewer connection edges due to the smaller number of students and a consequent smaller number of evocations. The term "Physics" is still remembered, having been cited nine times. However, this was not the term that received the most mentions, being surpassed by "quantity" (thirteen mentions). Some terms that may be related to quantum mysticism, as highlighted by Hilger and Moreira (2012), appear in this network, such as "seaweed", "sea animals", "sea" and "ocean", all being remembered once each. These are terms that according to Hilger and Moreira (2012) do not relate to Quantum Physics, so we did not want them to appear in a new network of similarities, formed after the application of the Didactic Activity.

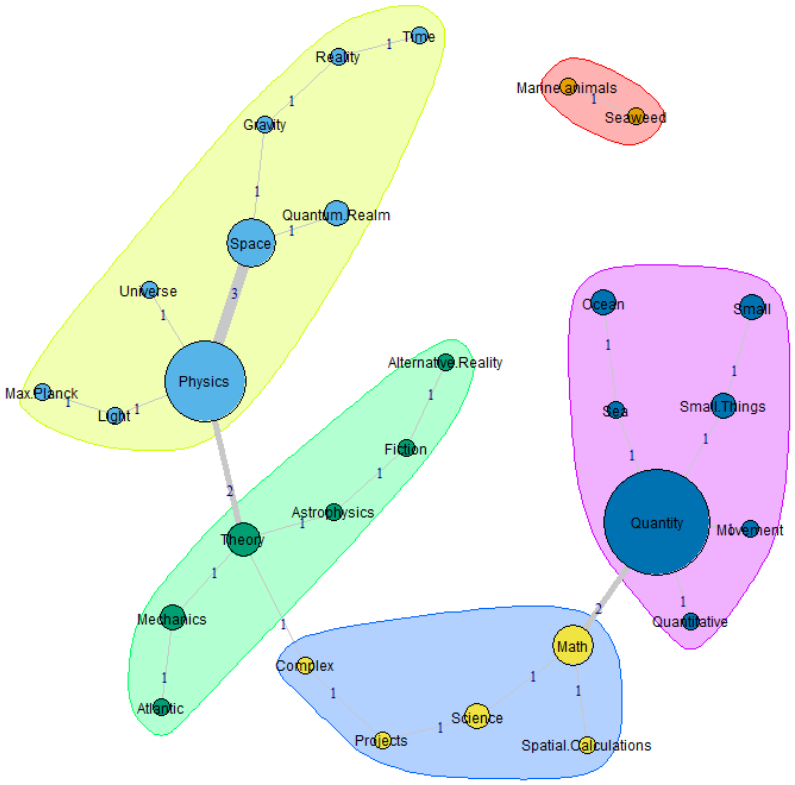

Fig. 4 – Similarity network of the class investigated at the beginning of the activities, with the students who were present in class at the time of application of this questionnaire (N = 30). Elaborated by the first author, 2021.

During the reapplication of the questionnaire, we noticed the emergence of a fundamental characteristic about the formation of a SR, foreseen by Moscovici in the TSR. In his work, Moscovici emphasizes the importance of communication and speech in the group, stating that people and social groups create representations during communication. Nevertheless, it is pointed out that researchers on SRs usually follow some methodological principles, the main one being the collection of samples of the conversations normally used in the social group, so with this in mind it was possible to analyze how the SR was shaped by its most important modifier, the speak. Some samples from student speeches collected by the researcher show how important communication was to shape the SR:

Student Fe.: Guys, do I put quantum coach here?

Student Ke.: No! Imagine ... putting quantum coach in this thing.

Student Ed.: Yes, how absurd, it has nothing to do ...

Student Fe.: Ok... ok ... I won't write.

Therefore, if the questionnaire was applied without allowing interactions, the student identified as "Student Fe" would probably have written the term "quantum coach", and we

would have in the similarity network at least one clear term related to mysticism. However, due to the communication / interaction / speech with colleagues, such term was not present, and the network was the one show in Figure 4 thanks to the communication between students, in an environment where they were free to do so. Nevertheless, Moscovici (2015) warns that the people who create the representations are something similar to amateur teachers, because they convince others of what they believe. In this sample of conversation, therefore, there is a first indication that some students, in this case Student Ke and Student Ed, may have behaved like amateur teachers, in the sense that they convinced their colleague that "quantum coach" was a term that should not be used to answer the questionnaire. Furthermore, when the researcher asked what they thought about "quantum coach", in the introduction of the didactic Activity in the first class, we had an interesting answer from another student, what tends to show how weak the presence of conceptions of mysticism was in the SR of this group:

Student An.: My sister bought a bioquantic mattress, I told her it was throwing money away. But ... she bought it anyway.

These data were collected at the beginning of the Activity and allowed us to have a good sense of the SR of the students in this class, and the nuances that characterize and establish a SR in a group, through speech. During the period of the Didactic Activity we were extremely careful in the choice and presentation of the content (HOERNIG, 2020), as a result of research with specialists in Quantum Physics at the Institute of Physics at our university (HOERNIG; MASSONI; HADJIMICHEF, 2021). After the Activity, we reapplied the questionnaire, repeating the FWAT procedure, asking students to answer what came to mind when they heard / read the term "Quantum".

On the application day, twenty-six students answered, resulting in a total of eighty-two expressions. A greater number than the questionnaire applied at the beginning of the Activity, even though less students answered (thirty answered the initial questionnaire and twenty-six the final one). We believe that the students' intuitive system, System 1 (KAHNEMAN, 2012), was possibly more elaborated after classes, towards a SR related to the content of Quantum Physics. These evocations were again analyzed using IRAMuTeQ, as previously done. We illustrate this last similarity network in Figure 5.

First, we observe that this new network of similarity approaches more what was considered by us as the reified universe of Quantum Physics. There is no term associated with mysticism. Several terms that are classified as belonging in the reified universe appear in this new SR, such as "Photoelectric Effect", "Interference" and "Diffraction". We also observed the names of Max Planck, mentioned four times and Einstein, mentioned twice, following our order of presentation of the Didactic Activity, and considering the historical emphasis that we gave in the work of Max Planck (HOERNIG, 2020), this name was significant to the group.

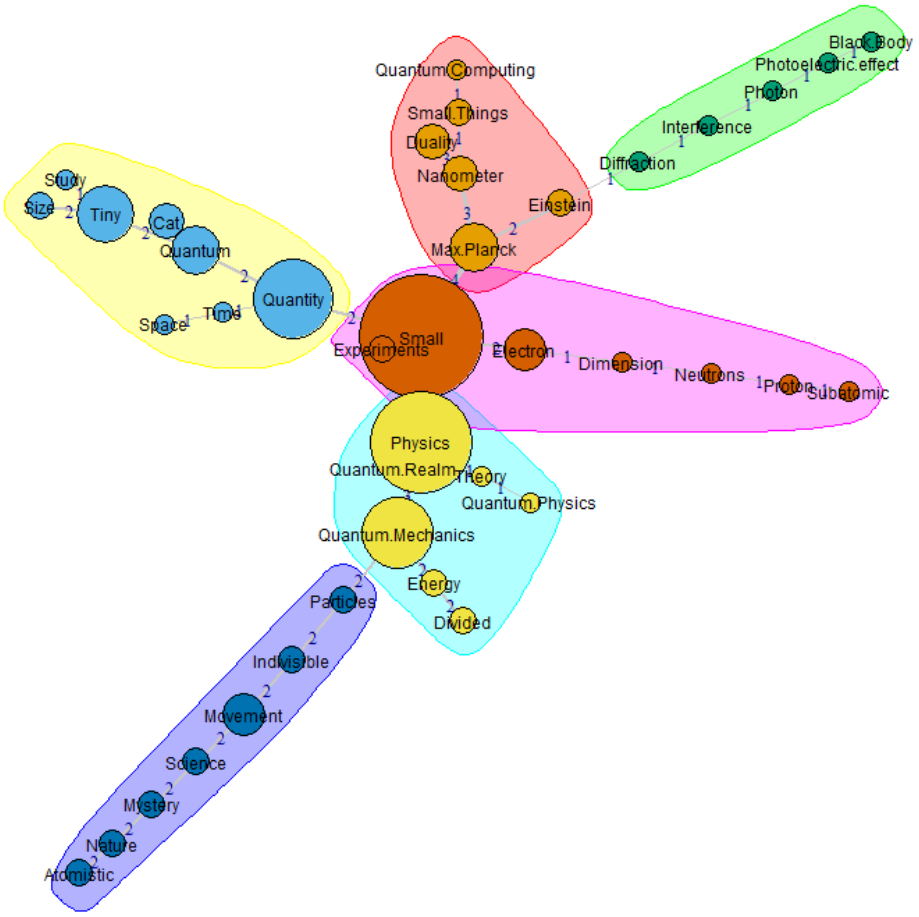

Fig. 5 – New network of similarities based on the final questionnaire (second half of 2019) (N = 26). Elaborated by the first author, 2021.

In the central part of the network, "Physics" remained (remembered seven times), but sharing the central aspect of this network of similarity with "small", given that the students seem to have assimilated that the Quantum Physics is the study of very small phenomena. In addition, as Moscovici (MOSCOVICI, 2015) warns, this network of similarities that is related to the students' SR should not be seen as a modification of the old one, on the contrary, the old SR is abandoned and a new representation is formed, which may have characteristics in common, which will be more likely to be observed in the nucleus. In fact, this is what we observed, a new network of similarities considerably different from the previous one, with some few similarities in the central part.

The term "small" shows itself as an interesting situation, since before it received few evocations and now reappears, but with a central character. Water-related terms such as "Atlantic", "seaweed" and "marine animals", which were shown as peripheral terms and which were identified by Hilger and Moreira (2012) as related to notions of mysticism, are no longer present in the new similarity network. Generally speaking, by analyzing the similarity networks, we believe it is possible to infer that a SR closer to the reified universe was

achieved, indicating that a general learning of the content took place, with the occurrence of a certain degree of scientific literacy, since related terms to the scientific reified universe for Quantum Physics have been observed in the new network of similarities and, therefore, to be somehow present in the SR of the group of students.

V. Conclusions

With this work we analyzed some possibilities for research in Quantum Physics (QP) Teaching, focused on High School (HS), using the Theory of Social Representations (TSR), and a methodology that is characteristic of it, the Free Word Association Text (FWAT). The TSR makes it possible to build networks of similarities of different social groups, which maintain relations with the Social Representations (SR) of the groups, allowing the researcher to identify ideas students have about some topic, in the case of QP teaching, it may help verifying if students have misconceptions that may be linked to quantum mysticism. We present a detailed analysis of an important work used in Brazil on Social Representations written by Moscovici (2015), in addition to empirical results from applications of short questionnaires in HS, as well as during the application of a Didactic Activity. The use of TSR was relevant for the introduction of QP in HS, allowing the *beginning* of an adequate scientific literacy, in our case with an emphasis on conceptual learning (other approaches are possible), given that students, after the application of the Activity, showed evocations closer to what was understood as the reified universe for QP.

In order to provide a SR of QP aligned with the current scientific knowledge, it is relevant that the teacher or researcher dedicates some time to investigate the SR of the students before an intervention, since this constitutes a strong possibility for identifying misconceptions about QP and ideas that may be far from the so-called reified universe. To identify the desired SR, in line with the scientific knowledge from the reified universe, there are different possibilities. For example, in our research (HOERNIG, 2020; HOERNIG; MASSONI; HADJIMICHEF, 2021), we conducted interviews with physics professors from our university, to identify topics of QP that should be included in the Didactic Activity, in a similar way conducted in the study of Krijtenburg-Lewerissa, Pol, Brinkman and Van Joolingen (2019). With the topics identified, it was possible to conduct a Didactic Activity that dealt with what is identified in the similarity network as something negative, such as mystical ideas, and encourage the discussion of the topics understood as belonging to the reified universe. This can be a fruitful way to improve the teaching of QP, and to train more reflective students on themes of Modern Physics, so absent from the classrooms of Brazilian schools.

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