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***Review paper***

# Initial perception of high school students for the study of space-time quantization applied to black hole entropy

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**Abstract**

The work presents the initial perception of the students through a diagnostic questionnaire, where the research comprised part of one of the works carried out on the "Study of the quantization of space-time applied to the entropy of black holes" with 23 students of the 3rd year of high school in São Cristóvão, Rio de Janeiro, Brazil. The project is part of several subjects introduced on modern and contemporary physics, as well as frontier research themes, aiming at the student-researcher posture and based on the learning theories of Bruner and Moreira, develop significant learning and receive new information and concepts at an elementary level, conditioning for a critical and reflective posture. The questionnaire was applied, and we raised a discussion and analysis of the students' results to verify the initial level of understanding to introduce a more in-depth study.

***Keywords***: *Diagnostic Questionnaire; Perception; Spacetime; Quantization; Black Holes.*

## 1. Introduction

It is always challenging to involve students with research projects in the classroom, especially with topics of modern physics, among other frontier topics, because the challenge is in the teaching-learning relationship.
The challenge in the case of the teacher is to research, study, delve into the theme and through very abstract language, understand the whole process and reduce it to a language, where its target audience becomes high school students, in addition to establishing goals for the research and creating tools for simulations and questionnaires throughout the activities.
In the case of the students, called "student-researcher", they will be conditioned to a research environment, developing work up to the final goal, which is the quantization of space-time applied to the entropy of black holes.
This article aims to present one of the works developed in the classroom, which is the application of a diagnostic questionnaire, precisely to analyze and discuss the results of students in relation to their perceptions about space-time, black holes and quantization.
The article will present the application of this questionnaire with 23 students of the 3rd year of high school in São Cristóvão, Rio de Janeiro State, Brazil, according to the methodology presented, as well as the analysis and discussion of the results.

## 2. Methodology

Before carrying out a research work in the classroom, we decided to apply a diagnostic questionnaire, as it is essential to know the profile of the students in relation to the understanding of the subject, with guidance to sensitize in practice and in the significant understanding of their training, obtaining advantage in the expansion of perspectives, reflections, among others [1].
Within this thought, the idea is not to judge, but to make a diagnosis to find more appropriate and satisfactory solutions, as the challenges due to the obstacles they will face are natural, aiming to complement a way of welcoming students [2].
The diagnostic evaluation presents us with a way to know what the student knows or does not know, as well as certain points that will accompany the understanding of the proposed subject [3].
The students have been developing research work and the topic to be introduced is already part of one of their great curiosities, because one of the greatest interests when it comes to science is to know something more about the universe, planets, galaxies, stars, black holes, topics related to astronomy, that is, with a connection to physics [4].
The work in a broader way, was developed according to com Moreira [5], through dialogicity and criticality throughout the activities developed by the teacher, proposing challenges, inserting conceptual instruments for students to think and model the universe [6].
We seek a change in the classroom in the adoption of criteria such as learning to know, learning to do and learning to be by living together, valuing thought, with more dynamic and effective learning situations [7].

The objective of this work is to present the initial perception of high school students for the introduction of a very challenging topic of frontier physics on the study of the quantization of space-time applied to the entropy of black holes. We developed a diagnostic questionnaire to analyze students' perceptions of space, time, quantization, and black holes.
The questionnaire was applied to a class of 23 students from the 3rd year of high school, in São Cristóvão, Rio de Janeiro, Brazil, with the identification of the names of students from A, B, C, ..., W. Its application took place on the first day of a meeting with the students individually, lasting 50 minutes. The questionnaire consists of nine discursive questions and three yes or no questions.
The questionnaire does not have a ready, right or wrong answer, as the objective is to extract information from students regarding their initial perception of the topics covered [8].

- Diagnostic questionnaire

1) What do you mean by space?
2) What do you mean by time?
3) Have you ever heard of space-time? If so, what do you believe to be space-time?
4) Do you believe that space is continuous "like a sheet of paper", discreet "like grains of sand" or both?
5) Do you think space-time can be interpreted geometrically with a set of polyhedra "geometric figures in three dimensions"? ( ) Yes ( ) No
6) Have you ever heard of quantization? ( ) Yes ( ) No
7) Have you ever heard of a particle's spin? ( ) Yes ( ) No
8) What do you mean by black hole?
9) Have you ever heard about entropy? If, yes, what do you believe yourself to be?

## 3. Analysis and discussion of the results

The approach to space and time is questioned until question 5. In general, the students responded naturally through empirical knowledge, which was to be expected, because through contact with the media, movies, they develop their perception of the world.
The first question asks what the student understands about space. In general, students believe that space is like a displacement, needing to move from one point to another. As they study in the mechanics part about speed, space and time, then, this concept is probably clear in the student's perception, making a natural association also with time, even though the question is only about space.
Other students considered space to involve everything around them, everything that involves existence, considering it in a global way. There are students who consider it local, because it needed the presence of a body to make sense of the existence of the space.
There are students who directed their thoughts to an infinite space, considering the immensity and because they did not access such a dimension, they believed it to be infinite. Some quotes about the students' first question: "I think space is the universe." (C). "It is what surrounds us." (R). "I believe the place where everything happens." (D). "Everything that is around us". (H). "Space is the formation of stars that were caused by the big bang." (V). "Space in general is a vast place either on Earth or outside it." (Q). "A dark, infinite place, full of planets and stars." (T). "I understand that space is the distance or instant of a certain object." (M). "It is the position in which everything is." (L).
The second question deals with the understanding of time. The vast majority believe it is time, using units of measurement, such as seconds, minutes, hours, days, months and years. Responses of this type are expected, precisely because of the daily life of students in the use of clocks and calendars for events and basic activities, requiring the time of entry and exit in places.
Other students considered the weather associating it with the weather, as they hear the question like: "what is the weather like today?". Students who thought of time being associated with the weather, their understanding is whether it is sunny, rainy, cloudy or snowy.
There are also students who were more complex in the sense of critical sense, believing in their existence or not, depending on the point of view.
We can check some quotes from the students about the second question: "It is a way of knowing what happened, what happens and what will happen". (Q). "Time is a cycle that leads to the formation of hours, minutes and seconds". (V). "The hour and the climate". (T). "Time for me is sun, rain and time". (R). "Time is something that no one can stop". (B). "Seconds, hours, days, months, and years." (A). "It is the duration of things." (N). "Time is what we mark on the clock." (E). "Time for me exists and it doesn't exist, because I think it depends on the point of view". (H). "A mediation that allows us to know at what moment a certain event occurs". (S).
The third question addresses the student to those who have heard of space-time, which should be according to their concepts. In general, they believe that space and time need each other for events to happen, reflecting on the idea of dependence between these variables, initially conceptualizing space as displacement.
They also consider space-time to be a plane with dimensions in which elements can be defined. Mentally, they configure it as a map (position x time), as they talk about dimension and determination of points that can be defined by this map and 26% of the students have not heard of it or did not know how to answer.
We can check some quotes from the students about the third question: "It is a way of seeing reality that would be everything". (Q). "I have heard of both of them individually, but we live in them both in space and in time." (O). "I dare say that this is what happens in space at a given time." (F). "I think it's a connection between space and time, because it doesn't make sense to talk about displacement in space without talking about time." (I). "I believe it is a plane with dimensions in which the elements can be defined." (N). "It is a set of position and time." (K).
The fourth question asks the student if he believes that space is continuous "like a sheet of paper", discreet "like grains of sand" or both. They consider space to be Euclidean, of a continuous nature, perhaps because they believe in a space with a background, which they easily think of as a sheet of paper. There are students who consider it to be both because the space is malleable to any relationship. This identification is interesting, as it will depend on which point of view the study will be treated, interpreting here the concept of malleable as the flexibility, the elasticity with which the structure of the space can be described for a given event.
There are students who consider space discrete, as they associate it with the sum of stars and bodies belonging to the universe. Particularly, I consider this view of space to be discrete rare, due to the need to consider space as a fixed background, which naturally leads us to Classical Physics. The percentage was close to the students who believe it is continuous 40% and both 43%. Only 9% believe they are discreet and 8% did not know how to answer.
We can verify some quotes from the students about the fourth question: "Space is vast and infinite". (V). "I believe it is continuous like a sheet of paper, for it is what it involves." (A). "Both, for human understanding cannot yet measure space." (E). "I think discreet, because

without proper equipment we can't see." (B). "I think it's discreet, because almost no one has the answer." (D). "I believe it can be like a flat sheet and grains of sand like galaxies. Both!". (J). "I believe that space is malleable to any relationship." (P).
The fifth question asks whether the student believes that space-time can be interpreted as a set of polyhedra, "geometric figures in three dimensions". The question asks to answer yes or no and, in the graph, below, presents the percentage of students' answers [8].

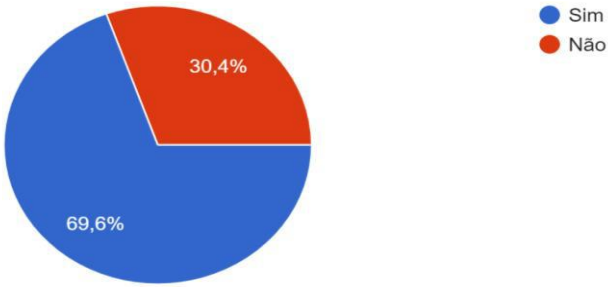


**Fig. 1:** Percentage Result of Students in the Interpretation of Space-Time Geometrically as A Set of Polyhedra [8].

We noticed in the first meeting of the study that many students can interpret space-time as a set of polyhedra. This perception is natural due to the treatment of dimension being associated with geometric figures and analyzing the answers about quantization and spin of a particle, which are questions 6 and 7 of the diagnostic questionnaire and the student perceives little contact with the term "quantization".
The sixth question asks if the student has ever heard of quantization. It is a matter of yes or no and we can see the percentage of the class in the graph below:

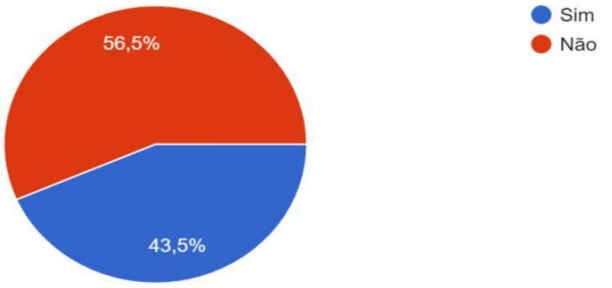


**Fig. 2:** Percentage Result of Students Who Heard of Quantization [8].

This deficiency is due to the preparation of the subject in the classroom for the treatment of aspects involving quantum mechanics.
The seventh question, also of yes or no, asks if the student has ever heard of spin of a particle. About 60.9% of the students have not heard of the spin of a particle, since the Chemistry classes, which includes in the High School curriculum, the class of electronic distribution, quantum numbers, with the orbital treatment of electrons using the periodic table.

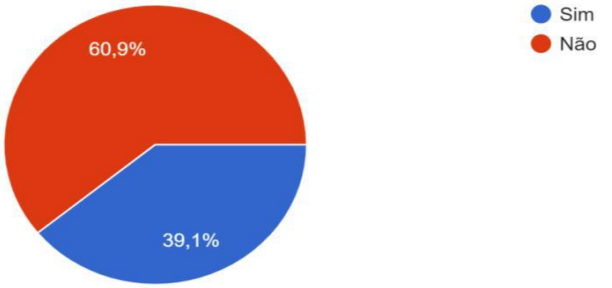


**Fig. 3:** Percentage Result of Students Who Heard in Particle Spin [8].

Checking the answers about black holes and entropy in questions 8 and 9 of the diagnostic questionnaire, the eighth question asks what the student understands by black hole. In general, they believe it to be like a spherical body, as they access movies and cartoons, and these images are well established in their minds. They believe it is like a black ball that swallows everything around it, others already define it as a whirlpool that also sucks everything around it, thinking like a sink drain, where the water travels a spiral trajectory, entering the drain. There are students who consider nothing and not even light to be able to escape the black hole. We can check some quotes from the students about the eighth question: "A black hole is a thing that grows and swallows everything". (B). "A giant thing that sucks up anything that comes near it." (O). "A black hole would be what scientists think will lead to another world or another reality." (C). "A black hole is a mass with gravity so large that not even light can escape." (M). "That everything that goes in never comes out." (A). "The Death of a Star." (K). "It is a region of space that has a very strong gravitational field." (Q). "Like a drain and it sucks everything." (E).
The ninth and last question of the diagnostic questionnaire asks if the student has ever heard of entropy and if so, what would he believe it to be. There are students who believe it leads to chaos, due to the study's understanding of "disorder" that the concept of entropy defines a priori. Another student believes it is a way of measuring the particles of a system, which does not escape the ratio of the amount of heat to temperature, or proportionality to the event horizon area of the black hole, although it is not a measure in itself, but a kind of "counting".
There is a student who answers by asking: "Would entropy be the effect caused by the black hole?" (R). I believe that your answer to this question already gives an idea of a deep critical sense associating it with the previous question about black holes. Because entropy is not caused by black holes, because we can analyze entropy for several systems, but the interesting thing is the relationship that this student makes with the term entropy.

We can check some quotes from the students about the ninth question: "I believe it is a system that leads to chaos". (F). "I believe it is something that measures the particles of a system (in a shallow thought)". (S). "The degree of disorder of a given system". (B). "I don't remember, but it must be something related to temperature." (L). "Would entropy be the effect caused by the black hole?" (R). Most students did not know how to answer, totaling 69.5%. Only two students have heard of it, but they didn't know what it was about [8].

## 4. Final considerations

The diagnostic questionnaire was the first activity carried out with the students to introduce the study of the quantization of space-time applied to the entropy of black holes. The application of the diagnostic questionnaire was essential to make the necessary adaptations throughout the activities, in view of the students' reality.

The questionnaire was developed with important questions for the teacher's understanding of the topics that would be addressed in the future, because the future work would be to condition the students to question and think critically about reality, working in teams, analyzing the proposals presented, trying to solve the experimental simulation activities, as well as the games.

But in general, the results of the diagnostic questionnaire show the way students understood space and time, obviously answering according to their realities and empirical experience on the subject, in the same way with the black hole.

Only in the quantization approach, we realize the lack of information, because really, few schools address quantum physics and when they do, they deal with it superficially.

The work in its greatest scope has already been developed with the students and in the future, we will develop the data of a questionnaire after the study of the quantization of space-time applied to the entropy of black holes.

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