

The teaching of the Atomic Structure from the Quantum Theory in the light of the didactic transposition^{+,*}

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Abstract

The objective of this research article is to establish how the atomic structure is taught by Colombian teachers and if conceptual elements of Quantum Theory are taken into account in it. The study was carried out from the theoretical perspective of Didactic Transposition. The sample of the same were 71 teachers from different regions of Colombia who work as teachers of secondary, especially tenth grade. The results indicated that the topic of Atomic Structure is not approached from the conceptual basis of Quantum Theory, that there are important confusions in some fundamental concepts related to the duality of quantum objects, indeterminate relationships, energy levels, among others, which configures a scarce teaching, based on atomic prototypes, formalist and with conceptual errors.

Keywords: *Atomic Structure; Didactic Transposition; Teacher Training.*

⁺ La enseñanza de la Estructura Atómica desde la Teoría Cuántica a la luz de la transposición didáctica

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I. Introduction

The teaching of atomic structure in Colombia is a developing field of research and the results presented below correspond to a portion of those obtained in the doctoral research entitled “Teaching of Atomic Structure in Secondary Education in Colombia” and seek to contribute to the recognition of this line of research, which is important for science education in a country like Colombia. To evaluate the teaching, the curricular documents issued by the Ministry of National Education were previously analyzed, which are the current regulations for the Colombian Educational System (SOLBES; MUÑOZ BURBANO; RAMOS-ZAMBRANO, 2019) and also the textbooks that teachers use as support both in the planning and development of their classes (MUÑOZ BURBANO; SOLBES; RAMOS-ZAMBRANO, 2020).

This must be completed with the analysis of how teachers assume the subject matter in the classroom. This leads us to pose the question that constitutes the problem: How do teachers teach the basic concepts of Atomic Structure in secondary education in Colombia? This question seeks to know the topics related to the teaching of atomic structure in secondary education, paying special attention to whether within these topics, the conceptual basis of quantum theory is addressed. Ultimately, it seeks an explanation of the reasons that lead to the observed teaching approach.

In order to answer this question, it should be taken into account that the teaching of atomic structure (AS) from the basis of Quantum Theory, in countries such as Brazil, Spain or Argentina, is a prolific research trend with important results (LOBATO; GRECA, 2005; PAULO, 2006; FANARO, 2009; FERNÁNDEZ; GONZÁLEZ; SOLBES, 2005; PENA, 2006; SAVALL, 2015; TUZÓN; SOLBES, 2014, 2016; MARTÍNEZ; SAVALL; DOMÉNECH; REY; ROSA, 2016; CASTRILLÓN; FREIRE; RODRÍGUEZ, 2014). This situation is not yet consolidated in Colombia; hence the development of this research starts from the question that would constitute the problem: How do teachers teach the basic concepts of Atomic Structure in secondary education in Colombia? This question seeks to know the topics related to the teaching of atomic structure in secondary education, paying special attention to whether within these topics, the conceptual basis of quantum theory is addressed.

In order to give an answer to this problem, a hypothesis is proposed that allows establishing a methodological process to confront it: “The teaching of atomic structure in Colombia is scarce, descriptive, formalistic and does not take into account the quantum theory, therefore, it is configured as a source of errors”. For the development of this hypothesis it is necessary to specify that it is assumed as a scarce teaching: that which addresses atomic models up to the Bohr model, excluding the quantum model and therefore, topics of quantum theory; descriptive, teaching that only performs a chronological narration of the atomic models, without a critical analysis of their background and limitations; and formalistic teaching, when it focuses on mathematical formulas and equations, without

experimental work and without addressing socio-scientific issues (SOLBES; MUÑOZ-BURBANO; RAMOS, 2019).

II. Theoretical Framework

From this perspective, we start from the fact that in secondary schools, significant changes are required in what is taught, and therefore it is important to know the didactic and disciplinary training of natural science teachers, since teacher preparation is the cornerstone of any renovation in science education (ACEVEDO, 2009; MARTÍN-DÍAZ; JULIÁN; CRESPO, 2013; KLEICKMANN *et al.*, 2013). For the specific case of the teaching of Quantum Theory, didactic research has allowed us to deduce that, one of the aspects that has most limited its teaching is the preparation of teachers (KALKANIS; HADZIDAKI; STAVROU, 2003; FANARO, 2009; GRIEBELER, 2012; SAVALL *et al.*, 2016).

We consider the Theory of Didactic Transposition, defined by Chevallard (1985), as an efficient instrument to analyze the process by which the knowledge produced by scientists, which has been called Wise knowledge, becomes knowledge for teaching. We start from the premise that the transformation that occurs in knowledge cannot be a mere simplification, since it is a “new” knowledge that responds to two different epistemological domains: science and the classroom (BROCKINGTON; PIETROCOLA, 2005).

Now, if the teacher is not responsible for the production of scientific knowledge, teachers are responsible for the knowledge generated in the classroom, therefore, they are responsible for how much scientific knowledge is transformed, avoiding errors, omissions and the configuration of a very large gap between scientific knowledge and the knowledge taught.

This new knowledge, which will be the product of reasonable transformation, must meet certain requirements: be understandable for students, be contextualized in time and in the students' characteristics, correspond to the knowledge accepted by the scientific community, not have been distorted, trivialized or deformed and therefore generate errors in its teaching and learning; hence the possibility of analyzing teaching from the Theory of Didactic Transposition.

On the other hand, we consider it particularly important to review the transposition of quantum theory, because, as Chevallard (1985) warns, biological aging may occur, “the knowledge taught becomes old in relation to society” (p. 26). The concept of biological aging is understood as a non-conformity with the corresponding knowledge of the scientific community, either because the progress of research has revealed false results that are taught in school or because new acquisitions or knowledge have been elaborated (GÓMEZ, 2005). The above highlights a problem in the teaching of atomic structure, since specifically in this subject, models that science has warned of their inconsistencies for a long time are taught and quantum theory is not considered. The gap between the knowledge to be taught and the knowledge that has been denominated as wise, constitutes a gap that students suffer from, but that the teacher could try to close.

However, the teacher is not always aware of this distancing, therefore, it is necessary to verify that the knowledge that is taught on the subject of Atomic Structure is not distorted, does not lose its essence, or is trivial or contradicts with the approaches of the QT, as there is a risk of generating errors or being scarce.

Another important concept of this theory is the idea of Chevallard's Didactic System (1991), corresponding to a ternary relationship between the teacher, the learner and knowledge, as a fundamental constitutive element. To assume knowledge, as an important element for the system, is another reason why this reference is considered pertinent. As stated before, an analysis is necessary to establish a guiding thread attached to the development of QT in the teaching of atomic structure, to determine those conceptual and epistemological elements necessary to achieve its understanding, as well as scenarios that would facilitate epistemological breaks related to the counter-intuitive aspects of QT.

From the perspective of the Theory of Didactic Transposition, each content will generate a different didactic system when it is taught. Obviously, the context in which it is taught will give a special nuance, as well as the resources used, which together generate a transformation. When the teacher establishes a planning process of what, how, when, with what and to whom they teach, they should foresee how much knowledge is transformed and how to prevent the transformation from becoming a distorted knowledge.

In this sense, Chevallard's didactic transposition offers a prolific frame of reference for the analysis of the data and the structuring of a proposal for teaching and learning. The need to investigate teachers' strategies for teaching atomic structure lies in the fact that "the possible didactic transpositions for secondary school depend to a great extent on a solid conceptual formation" (OSTERMANN; PRADO, 2005, p. 194), therefore, from the answers obtained, the conceptual formation of the teacher is related to whether the knowledge is transformed for teaching or is distorted.

It should also be noted that the theory of didactic transposition has been questioned for not considering the role of the state and educational administrations within it, which leaves out the elements of hegemony and ideology that are constitutive of the process itself (CARDELLI, 2004).

III. Methodological Approach

The development of this research is described, from the perspective of Bisquerra (2004), as an educational research. The type of design chosen for the research is quasi-experimental, since the subjects are not randomly assigned to work with them; the groups are formed and their sampling is intentional. In order to confront the hypothesis, the following objective is proposed: to characterize the teaching of Atomic Structure in Colombia and its relationship with QT.

To characterize teaching, a questionnaire was designed for 71 working teachers in secondary education. The sample includes teachers from different specialties and places of work: 17 teachers work in private institutions and 54 work in the public sector. Of the total sample, 21 of the teachers work in the rural sector and, therefore, 50 teachers work in the urban sector.

In Colombia, teaching can be performed by graduates and non-graduate professionals. Bachelor's degree programs are offered by higher education institutions, with a duration between 8 and 10 semesters, and enable the graduate to teach at different educational levels, areas or populations, depending on the emphasis of the formation. Non-graduate professionals are those who have received training in the disciplinary field or as engineers, but have no training in didactics and pedagogy. For this reason, the training of the teachers to whom the instrument was applied is described below: graduates in Chemistry 13, in Biology 6, in Natural Sciences and Environmental Education 12, in Biochemistry 1, in Biology and Chemistry 14 and non-graduate professionals: Chemists 17, Chemical Engineer 1, agroforestry engineers 6 and zootechnician 1. The graduate in Chemistry in Colombia is prepared to be a teacher of, in this case, physics or chemistry, the Chemist does not work in his training anything that has to do with pedagogical or didactic components.

In the questionnaire, the questions were oriented from a didactic perspective, which made it possible to characterize teaching, related concepts, strategies, and time spent in the development of the topic. The objective of the instrument was not to evaluate the teachers' knowledge of the topic, but rather to find out whether and how the topic is introduced in the classroom.

The instrument was subjected to validation. Validation was done with the purpose of determining specifically whether the instrument measured what it was intended to measure or was suitable for the purpose for which it was created (COHEN; MANION; MORRISON, 2011). Any research instrument that undergoes validation must have two quality criteria: validity and reliability (ROBLES GARROTE; ROJAS, 2015). With respect to validity, a group of 5 experts were asked to give their opinion on the content and the way the instrument was designed, to determine whether the questionnaire addresses the thematic of the research and points to the objective of determining how atomic structure is taught. With respect to reliability, understood as the degree to which an instrument measures accurately and rules out error (ROBLES GARROTE; ROJAS, 2015), the Cronbach's alpha value of 0.762 was obtained (a value between 0.70 and 0.90, indicates good internal consistency).

The questionnaire consisted of two parts. The first part consisted of closed questions, these items relate school praxis and planning, the degree of acceptance and the use that teachers give to textbooks. The second part corresponds to 10 open questions, the statements of which appear in the tables of results 1 to 10, therefore, it is requested to answer with all the information that the teacher considers convenient, in addition, there is the possibility of expanding through an interview.

IV. Discussion of results

The results obtained for the first four items coincide with previous research, specifically in that teachers use the TBs for school planning, especially to determine the curricular contents and standards to be developed, This makes the TBs mediators between the standards established by the Ministry of National Education (MNE) in the case of Colombia and school planning, hence Martínez (2002), Sacristán (2005) and Solarte (2006), assume them as mediating tools, which translate and concretize those meanings included in the standard prescribed by the institutions that regulate the educational systems.

With respect to the second part, the following results are obtained.

Table 1. Teachers' results for item 1 – Part Two.

Item	Internet	Scientific Texts	Internet and scientific texts	None	MNE
In the case of not using textbooks in the planning of AS teaching, what other elements do you consider?	46.4 %	14 %	21 %	6 %	12 %

Note: Elaborated by the author.

Table No. 1, describes the results of item 1, which aims to relate the teaching that teachers relate to textbooks, this in that, these have also been analyzed and present important conceptual errors (MUÑOZ BURBANO; SOLBES; RAMOS-ZAMBRANO, 2020). Considering the results of the first part of the questionnaire applied to teachers, it is deduced that 80% of the teachers interviewed use the TBs as a reference in educational planning, a result that other researches also refer (HERNANDEZ, 2007; BRIGAS; MARTINS, 2005; BARRIA *et al.*, 2016; VILLARROEL, 2019). When asked, in addition to the book or instead of the textbook, what other elements they consider convenient to take into account in planning, it was established that 46.4% of teachers prefer to use the Internet, in any of its modalities, searching the network for scientific texts or free access pages that support their process.

It is worth mentioning that, among the teachers who do not consider textbooks in the school planning process, there are mainly teachers with a degree in chemistry. They consider scientific articles or books other than textbooks to be a better source of knowledge. On the contrary, graduates in natural sciences and environmental education and other non-graduate professionals also state that textbooks are a good source of consultation in their teaching work. These findings confirm the importance of analyzing the content of textbooks, since they are still a source of reference for teachers.

Table 2. Teachers' results of item 2 – Part Two.

Item	Conceptual- Propaedeutic	Environmental	Epistemologic	Not relevant	No answer
Why do you consider it important to teach AS in secondary education in our country?	88%	6%	3%	1.4%	1.4%

Note: Elaborated by the author.

Table 2 describes the results of the second item, this question aims to know what conceptual and epistemological weight teachers give to the teaching of AS. For the analysis of this item, some recurrences were established, the option that obtained a higher percentage equivalent to 88%, are teachers who attribute a conceptual and propaedeutic importance to the teaching of AS (AIKENHEAD, 1994; FENSHAM, 2004), the reasons they argue are that this subject allows understanding other subjects or that knowledge in AS is required to understand basic knowledge for higher education grades, without specifying contents or concepts.

Only 3% of the teachers refer to an epistemological significance, denoted by the importance of showing the nature of scientific work and the process of science construction. It is noteworthy that 6 % of the teachers argue that the importance of teaching AS lies in the fact that it allows encouraging environmental care. However, this argument lacks specific contents that configure the relationship; rather, it is an uncritical presentation that all the contents of natural sciences should aim at generating an awareness of care and conservation of the environment.

It is important to emphasize that atomic structure is one of the structuring conceptual cores of both physics and chemistry (HENAO-GARCÍA; TAMAYO-ALZATE, 2010) and teachers should also relate the need to understand atomic structure in order to understand its properties, periodic ordering and bond formation, exceptions to the octet rule, structure of molecules, hybridization of the carbon atom, among others.

Table 3. Teachers' results for item 3 – Part Two.

Item	Classics	Pre- quantum	Quantum
What contents do you consider convenient to develop the topic of Atomic Structure?	82%	14%	4%

Note: Elaborated by the author.

Table 3 describes the results of the third item; the objective of this question is to know the topics that teachers relate to the teaching of AS and, therefore, to determine whether they relate quantum concepts. When analyzing the teachers' answers, three inductive tendencies were generated: those teachers who determine purely classical contents, which correspond to 82%, within these contents the most predominant are: classical atomic models

and their history (DALTON; THOMSON; RUTHERFORD), subatomic particles, behavior of atoms, and what is matter.

The second trend corresponds to teachers who mix classical and quantum contents, which corresponds to 14 %, and was denominated pre-quantum. This group refers to specific contents of quantum theory such as: quantum numbers, the “uncertainty principle”, together with contents referred to in the previous paragraph. The third trend, which corresponds to 4%, refers to contents related to wave-particle duality, the “uncertainty principle” and quantum numbers.

This question is based on establishing the importance of content in the didactic system, a fact that becomes clear after the work done by Chevallard and researchers of the French school, where it is established that knowledge is an object of analysis within the system (CARVAJAL; VÁSQUEZ, 2012).

Table 4. Teachers' results for item 4 – Part Two.

Item	Classic	Pre-quantum	Quantum
What strategies do you use for the teaching of energy levels?	93%	7%	0%

Note: Elaborated by the author.

Table 4 describes the results of the fourth item, this question has the objective of knowing the strategies that teachers refer to in the teaching of AS, this also allows linking the topics, strategies and resources used. In relation to the strategies, it allows reviewing the process of didactic transposition, since the description allows determining whether the knowledge may suffer important deformations. For the analysis of this item, 2 recurrences were established, which are: strategies with a pre-quantum approach and strategies with a classical approach, according to the description made by the teachers. A third group was expected, which would be the one describing a quantum approach, but there were no responses allowing the structuring of this group.

The 93% of teachers refer to diverse strategies, but with a classical approach, for example, when referring that they use analogies of the atom as “a small solar system where electrons like planets revolve around the nucleus through energy paths (sic)” or as evidenced in the following response that alludes to a pseudo-scientific esoteric sense as “atom: human being (soul, spirit, body) (sic)” (PC3). Within this approach, 70% of the teachers refer to the use of videos, which they consider very complete and clear. When asked to expand or specify the type of video, it is obtained that they are web resources that work from analogies or classical descriptions.

The scale models occupy a significant percentage of approximately 60% within this theme, which is striking, since they refer to scale models that involve the filling of the levels as well as the atomic orbitals. The teachers state that the scale models used are made of

recycled material, which in their opinion makes them more valuable. However, it is clear that the statements of Chamizo (2010) are not known, when explaining that models (m) are representations, generally based on analogies, which are built by contextualizing a certain portion of the world (M), with a specific objective, since the scale and correspondence in the models and scale models used in teaching are not recognized.

In the case of the construction of scale models related to atomic models, a problem arises, as with other concepts, since there are transformations on the original scientific models. In this case, especially in relation to the size, scale and dynamics of the atom, which is evident in the construction of scale models, where the size of the electrons is basically the same as that of the entire nucleus.

For strategies with a pre-quantum approach, which corresponds to 7%, there are those in which teachers refer in some way to work related to Bohr's atom and atomic spectra or experimental practices related to Bohr's model, a situation that is striking, since there are not many experimental practices in this field, beyond a homemade spectrometer, which none of the teachers mentioned.

The strategies described allow inferring that in the teaching of energy levels, teachers prefer analogies in which layers and filling spaces are referred to, as well as the realization of electron filling exercises. These forms of teaching may seem dynamic and generate clarity in learning, but as described above, scientific knowledge is distorted, evidencing important errors in teaching. Analogies are understood as a comparison between the known and, in this case, the little known, which are the energy levels. The concern of describing the orbital and energy levels as spaces that the electron may or may not occupy, i.e., shelf orbitals that exist independently of the electron, is ratified (SOLBES 2018).

Table 5. Teachers' results for item 5 – Part Two.

Item	Classic	Quantum	Confusion	Does not work
What strategies do you use for teaching quantum numbers?	84.5 %	4.2 %	10 %	1.4 %

Note: Elaborated by the author.

Table 5 describes the results of the fifth item, this question aims to know how quantum numbers are taught, if they are derived from the wave equation or, on the contrary, there is confusion when relating them to Bohr's or Sommerfeld's atom. As in the previous item, according to the approach referred by the teacher, two types of strategies were established, those classical and those explained from a quantum approach, a third group was required, which reaches 10%, in which confusion is evidenced in the concepts referred by the teachers, such is the case of relating quantum numbers with the mass and atomic number.

Within the strategies with a conventional approach corresponding to 84.5%, metaphors, analogies and models are described. There is also regularity in mentioning the use

of graphs and diagrams. Other teachers state that this is a very theoretical subject and that, in this way, it is necessary to work on it. Finally, in this group with a conventional approach, videos are referred to by teachers as a didactic resource for the subject.

Only 4.2% of the teachers explain that they start from Bohr to arrive at the Schrödinger quantum numbers (PC4), although the explanations are not detailed.

Once again, the description of the strategies for teaching quantum numbers evidences conceptual confusions, which in the didactic transposition carried out deform the knowledge, thus generating a circle that explains the errors in learning.

Table 6. Teachers' results for item 6 – Part Two.

Item	It does so and shows rupture	It does so and shows no rupture	Confusion	Doesn't do it	No response
What strategies do you use to explain the photoelectric effect?	4,2%	30.9%	19,7%	35,2%	9,8%

Note: Elaborated by the author.

Table 6 describes the results of the sixth item, the intention of this item is to know specifically if this topic, which has conceptual and epistemological importance, is taught, and if it is taught, this teaching is attached to the conceptual bases of Quantum Theory. Three tendencies were established in the teachers' answers: those who explain the photoelectric effect, those who state that they do not, and teachers who do not answer the question.

The teachers who explain the photo-electric effect reach 55%. Of these, only 4.2% give a correct description, since the rest do not show the break with classical physics or give confusing explanations. For example, the teacher who states working “with electric circuits in parallel and in series, making an electric circuit or comparing with decorative lights for Christmas” (PN9), confusing LED light with the photoelectric effect. On the other hand, teachers of this group state that this is a confusing subject, therefore, it should be worked in a theoretical and very general way. Only 4.2% of the teachers questioned stated that they explain the subject and emphasize the break with classical physics, even explaining the use of simple experiments.

The second group, which corresponds to 35.2% of the teachers, state that they do not work on this topic with their students and, among other reasons, they claim that it is a topic that is not included in the course contents or that they do not relate it to the development of atomic models.

A third group, 9.8%, simply does not give an answer to the question, and those to whom it is possible to emphasize why they do not answer it, give evasive answers that limit the continuation of the question. The above, generates concern, because, the photoelectric effect constitutes one of the breaking points between classical physics and quantum physics, by experimentally contradicting what was predicted by the electromagnetic theory and

because the explanation given by Einstein with the use of Planck's quanta, would reaffirm the crisis of classical physics (SOLBES; SINARCAS, 2010; SOLBES, 2018).

Table 7. Teachers' results for item 7 – Part Two.

Item	It does so and shows rupture	It does so and shows no rupture	Doesn't do it	No response
What strategies do you use to explain wave-corpuseular duality?	4.2 %	67.6 %	18 %	9.8 %

Note: Elaborated by the author.

Table 7 describes the results of the seventh item, following the line of the previous questions, this item aims to know not only the strategies, but also the conceptual foundation that these strategies have. The wave-corpuseular duality has conceptual importance because it is the basis of a new understanding of quantum objects, as well as epistemological importance. As in the previous item, three tendencies were established in the teachers' answers: those who explain the dual behavior of matter, those who state that they do not, and those teachers who do not give an answer to the question.

Although 71.8% of the teachers affirm that they work on this topic, the explanations they give are very limited and evasive, such as: “everyday examples of duality” (PP25), “experiments are performed” (PN5), or “videos because the topic is difficult to understand” (PN10). When asked how or which examples from everyday life or videos, there is no clarity in the explanation.

Another aspect that should be highlighted is that there is great confusion in the explanations, for example: “I use the analogy with a spinning top that seems to be still, but it spins and at the end forms a wave”, “this subject is approached in the laboratory with the help of a prism, measuring the wave-particle duality” (PN14). For other teachers it is a very theoretical subject and it is simply necessary to inform about it.

Two teachers state that they work on the subject from experimental situations that clearly explain and demonstrate the idea of dual behavior, as is the case of Yung's (*sic*) diffraction of light or “the double-slit experiment in a bucket of water” (diffraction and interference of waves) (PC4).

Within the group of teachers who state that they do not explain this topic are those who argue that it is a physics topic, that it is necessary to ask for support from physicists or that there are not enough resources for its explanation. A significant group of 9.8% of the teachers simply do not give an answer to the question, which is worrying, it is necessary that the teacher works with the student on the subject, it also requires a detailed analysis, because as Pereira, Ostermann and Cavalcanti (2009a and 2009b) point out, both teachers and students have difficulties in recognizing the characteristics of the dual behavior of quantum objects.

The teachers' arguments reveal a series of important difficulties, which in the light of

Chevallard's (1985) didactic transposition, are the consequence of not exercising epistemological vigilance to avoid both the aging of curricula and transposition with important conceptual errors.

Table 8. Teachers' results for item 8 – Part Two.

Item	It does so and shows rupture	It does so and shows no rupture	confusión	Doesn't do it	No response
Do you consider it convenient to incorporate the uncertainty principle (indeterminacy relations) in the explanation of atomic theory? Why?	4,2 %	40.8 %	26.7 %	21.1 %	7 %

Note: Elaborated by the author.

Table 8 describes the results of the eighth item, with an intentionality based on the epistemological importance of the relations of indeterminacy, which also in the light of the Theory of Didactic Transposition has suffered conceptual deformation, since it is referred to as the uncertainty principle. Therefore, the first precision that needs to be made is that the teachers who claim to agree with the inclusion of indeterminacy relations in the teaching of AS refer to them as the uncertainty principle. Although this group comprises 71.7% of the teachers consulted, there are responses that denote great confusion on the subject, for example: when mentioning that the “rural environment” is used for teaching (PP21) or that “it is simply all imagination” (PP8), or responses that state: “Yes, because it allows the student to understand the AS from the characterization of its mass, weight and other properties” (PP14).

Other answers that also denote confusion are: “Heisenberg introduces what the atom is for, it is not so important to know what it is like, but what it is for” (PP20), a conception that does not correspond to the indeterminacy relations. Or “it is necessary for students to understand that it is impossible to find an electron in a certain place, it is complex” (PC7) or simply “its equation is very complex” or “it is very complicated to teach and understand” (PP28), and that is why it must be done only in a conceptual way, or the use of an analogy “the school is the atom, the principal is the electron, it is complex to find the principal”.

Among the group of teachers who agree with working on this topic, they relate it to a problem of science as it is not finished or with the relativity of knowledge, that is, with a problem of lack of knowledge: “the principle shows that the theory is unfinished, it is under construction” (PP25); it is necessary to teach to “maintain amazement when not everything can be explained” (PN13), “everything is in continuous change” (PN16). As well as talking about duality, teachers argue that these topics “are complex and interesting” that “lead to the mysticism of science” (PC5), a theme that also appears in other works (HOERNIG; MASSONI; HADJIMICHEF, 2023), which could reveal pseudo-scientific ideas in teachers.

Twenty-one percent of the teachers say they do not agree with working on this topic because it is very complex and can generate confusion. Even the teachers themselves do not

feel prepared to address this topic, as evidenced by some arguments: “it should be considered whether to touch this topic with the students, since it can be a topic of confusion for the student, and if it is approached in a theoretical way only, it can represent the loss of interest of the student towards the macro topic that is sought to be taught” (PC6). “No, because I am not clear in the explanation of the atomic model, since it is relative in each period of history” (PP6), “not all teachers handle this knowledge, not for high school” (PP9). “No, because Heisenberg's indeterminacy principle is a complex and abstract concept, which requires the teacher to explain all the current axioms of quantum mechanics (mathematical postulates), and making this didactic transposition in secondary and middle school education, would be irrelevant, considering first that, the student should handle a high cognitive and metacognitive level” (PC2), “I do not know it” (PN6), “it is something advanced” (PC4).

Only 4.2% of the teachers refer to the importance of working on this topic and they do so BY thinking about the rupture between classical physics and quantum theory, arguing: “because the wave-particle duality is understood” (PN4), “to demonstrate the difference between classical and quantum” (PN7).

The answers allow inferring little clarity in the indeterminacy relations, they are described as part of the quantum theory, but their explanation is not precise. The answers are ambiguous, confirming what Giribet (2005) pointed out, when expressing that they generate confusion among those who face them for the first time; likewise, it also confirms the research that shows that the problems of learning modern sciences, especially in relation to modern physics, are not a consequence of the nature of the discipline as such, but of an incorrect orientation of its teaching and an uncritical way of introducing modern and contemporary concepts (SOLBES; SINARCAS, 2009; SINARCAS; SOLBES, 2013). In this aspect, under the notion of Chevallard (1985), scientific knowledge is being distorted as a consequence of an aged curricular system, because teachers have been trained with outdated curricula.

Table 9. Teachers' results for item 9 – Part Two.

Item	Yes conceptual	Yes technical	In some cases	No	No response
Do you consider it convenient to introduce QT to explain the atom in secondary education in our country? Why?	39%	4.4%	22.5%	28%	5.6%

Note: Elaborated by the author.

Table 9 describes the results of the ninth item, this question aims to know from what approach they consider important or not to include QT in secondary education in Colombia, due to the fact that its teaching is not specifically indicated in the curricular documents (SOLBES; MUÑOZ-BURBANO; RAMOS-ZAMBRANO, 2019). Although 65.9% of teachers consider it convenient to introduce the quantum mechanical model in secondary

education in the country, the reasons they adduce are related in 39% from the conceptual and from the purely propaedeutic purposes, as is the case of a need for higher grades or even university. The elements and reasons described below correspond to what Chevallard (1985) determines as “biological aging” because the urgency of a constant updating of the curricula and an epistemological vigilance that allows such updating is not assumed.

However, within this group it is necessary to relate answers that are not clear and are close to a pseudo-scientific use of quantum denounced by some authors (SOLBES, 2019; SANDIN, 2020), for example: “I consider that yes it is convenient, as the student will have the ability to understand their relationship with the universe and the natural world, giving rise to the importance of transcendence” (PP3), “quantum models allow us to enter into the mystique of science”, (PN14), “yes ...it is about knowing more to be able to make a model that provides and gives answers to many questions that are explained, using disciplines different from the sciences” (PN13).

It is also explained that it should be worked only in an informative way: “as history” (PN6), “I do not consider it convenient, but I do share it for general culture, because the relationship between the applied quantum, is far from the possibility in our areas” (PN7). “Yes, because it is not only a concept that applies to the structure of matter, but to philosophical thought processes, which have modified bases and principles given in previous years to this current boom of the atomic, nuclear and space age that have many scientists motivated to seek refuge on other planets” (PP5).

There is a group of teachers who relate the quantum-mechanical model with arguments such as: “to generate curiosity” (PP4), “to explore new ideas in young people” (PP5) or for “applicability in the professional field” (PC2).

Once again, environmental issues are specifically referred to in the thematic, with arguments such as: “Our country offers a variety of natural resources with this subject, it gives the possibility to investigate and delve into this topic” (PC5). We consider that the uncritical presentation in the relationship between the theme and environmental education is worrisome, since the teacher does not make a sustained presentation of his arguments, but rather it is shown as if it were always required to comply with the idea of teaching how to care for or value the environment.

A 4.2 % assumes that it is convenient to work on this topic, when explaining the relationship with current technology. Finally, only one teacher states that it is important to work on this topic: “not introducing it leaves the vision of science incomplete, theoretical work, not the equation” (PN4).

There is a group of teachers who condition the teaching of the mechanical-quantum model, even with the type of education: “we should work in greater depth in physics” (PP7), “only a little, because a lot of mathematics is needed and young people are not prepared, even I have to ask the physicists to help me” (PP8), “I would consider it convenient, however, in basic public education, especially, the necessary previous concepts are not available”

(PN12). “The level of deepening, of thinking development does not allow it in most cases. It is done in a mechanical and simply informative way” (PP25), “yes, but it is very complicated to teach and understand” (PP28), “not for all students, we should have a more focused education for the different professional performances of the students” (PN2).

Among the 28% of the teachers who say they do not agree with the teaching of the quantum-mechanical model, we find arguments such as: “no, not for secondary school” (PP9), “it is difficult for children to understand” (PP19). The 5.6% of teachers simply do not answer the question.

These results can be explained, in part, if we consider, as we have seen in the data of the sample studied, that in Colombia there are few physics graduates practicing in secondary schools. This may be due to the fact that there are few physics graduates and that they prefer other professional opportunities. And the training of physics teachers in the other degrees in Natural Sciences and Environmental Education, Biology and Chemistry, etc. that may end up teaching AS, only some of them have a deepening in physics or physical chemistry subjects that would allow a greater knowledge of quantum physics. Therefore, if secondary school teachers do not have knowledge of quantum physics, it will be difficult for them to carry out a didactic transposition of the same. And, as we have seen in items 5, 6 and 7, they will even incur in scientific misconceptions such as relating the photoelectric effect to an electric circuit. And, what is worse, in pseudoscientific or mystical ideas about quantum, as we have seen in item 8 on indeterminacy relations. We also observe a biological aging of secondary school curricula, since theories such as quantum or relativity are not contemplated in them. We believe that the educational administration and initial training institutions in Colombia should be aware of this situation, so that they can try to solve it by updating the curricula.

V. Conclusions

The analysis of the data allows us to conclude, in the first place, that QT is not taken as the main axis in the teaching of AS. Secondly, more than a didactic transposition, there is a deformation of the concepts and even a distortion of knowledge, teaching things that are in opposition to what is accepted by the scientific community.

With respect to the teachers' training, confusions in the topics related to quantum theory are relevant, and pseudo-scientific ideas are evidenced in 3 of the items, which did not explicitly ask about it. The strategies described by the teachers, although they are of generalized use, are not justified or explained in detail, which allows to infer an uncritical use. This is the case of the videos, which should be chosen with caution, since in their presentation there may be important conceptual errors.

Regarding the strategies used by teachers, the history of science is recognized as a very important didactic resource. However, its use shows that it is a chronological description of the facts that marked the development of atomic models, but this description is uncritical because, in addition to being anecdotal, it is not connected with socio-scientific situations,

hence it is assumed as a descriptive teaching.

Regarding the contents, teachers show confusion when explaining quantum phenomena and notions such as: photoelectric effect, duality of quantum objects, indeterminacy relations, energy levels, orbital and spin. The answers are evasive for these topics or describe teaching strategies that demonstrate the juxtaposition and mixture of classical and quantum concepts in their explanation. The analogies used and described are another element that allows us to deduce confusion in the teachers with respect to quantum notions, thus confirming what the didactic research says about analogies and also what refers to the elaboration of scale models, since the teachers when describing demonstrate that they transfer the concept directly to the analogy or the scale model, without determining its limitations or differentiating their errors.

On the other hand, the answers to the questions on the importance of teaching the quantum model are naive and more like an uncritical formalism. With respect to the teaching of indeterminacy relations and the duality of quantum objects, pseudo-scientific notions can be seen when relating them to transcendence or the action of energies. Teachers emphasize the teaching of symbolic aspects and calculations, as opposed to the structure of the atom.

The results described above corroborate the hypothesis that the teaching of atomic structure is scarce, descriptive, formalistic and does not address quantum theory, but is done from classical conceptions. And this shows symptoms of biological aging, in Chevallard's terminology (1985), of the Colombian Physics and Chemistry curriculum. Quantum is not taught in secondary education when we are in the era of quantum computing or artificial intelligence, recognized with the 2022 Nobel Prizes in Physics to Alain Aspect, John F. Clauser and Anton Zeilinger for their pioneering work in quantum information.

As we have already pointed out in the discussion, this can be explained, in part, because in Colombia there are few physics graduates practicing in secondary schools. And the training of physics teachers in the other degrees in Natural Sciences and Environmental Education, Biology and Chemistry, etc., only some of them have a physics specialization.

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