EPISTEMOLOGICAL RUPTURE IN THE DISCOURSE OF HIGH SCHOOL TEACHERS: THE CASE OF THE ATOMIC THEORIES

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Abstract In this research, we will preview the historic development of atomic theories since the time of the Greek until our days. This survey will permit to put in evidence the epistemological ruptures in the perspective of Bachelard (1968) or the paradigmatic change notion in the perspective of Kuhn (1970) that marked the evolution of the atomic theories, since the "naïve" vision of the atom until the modern quantum vision. We will describe the atomic models from Dalton to Heisenberg while tempting to show that they are in logical discontinuity, since the ways of constructing knowledge, imagined by all, are not founded on the same epistemological premises. Besides, this survey of the different models will permit us, thereafter to characterize in the discourse of Quebec chemistry and physics teachers, the epistemological rupture notion in the development of atomic theories.

1 Introduction

The research activities are related to the scientific representations of students at primary and secondary levels before and after intensive teaching. Different research studies have shown that students who attend science courses construct representations related to daily-life scientific phenomena, prior to any formal teaching. The daily-life phenomena include, but are not limited to: heat and temperature (Harrison et al., 1999; Romer, 2001), light (Mumbaa et al., 2015), states of matter and their transformations (Tatar, 2011), chemical transformations (Othman et al., 2008), law of conservation of matter (Özmen and Ayas, 2003) and behaviour of matter at microscopic level (Aydeniz and Kotowski, 2012; Boz, 2006). These representations often describe the scientific phenomena inaccurately and, more sadly, impede effective teaching (Duit, 2007).

What makes it so difficult to change students' misrepresentations of scientific phenomena? A body of researchers refer this problem to the fact that the students' prior representations are based on different epistemological assumptions of scientific theories. Therefore, the students often constitute a system of belief or a barrier that prevent them from changing their false representations (Bachelard, 1968). For example, the fundamental concepts of heat become a barrier to understand the kinetic theory of heat and motion of molecules. This resistance to conceptual change has also been observed with many scientists in history. Thus, this research will present a historical overview of the development of atomic theories from Greeks until present time in order to emphasize the differences between the atomic theories that have occurred over time. The study will also identify the representations of secondary school and college teachers as pertaining to this development.

2 Historic review of the atomic theories

It would be difficult to construct, in few lines, the history of the development of atomic theories. Consequently, this historic review will be limited in synthesizing the key step in the development of these theories from Greeks until the present time. In order to characterize these steps, we will use Kuhn's perception of scientific revolution (Kuhn, 1970). Note that, Kuhn believed that the development of science was not continuous, unlike what has been suggested by most of school textbooks (Leite, 2002; King, 2010).

This discontinuities that marked the stages of the development of the scientific knowledge constitute real ruptures in the sense of the philosopher and epistemologist Bachelard (1968), and by there, drive to change the explanations advanced by the scientists fundamentally. What are the discontinuities that characterize the atomic doctrines developed by Democritus, Dalton, Thomson, Rutherford, Bohr, Schrödinger and de Broglie, and others? Table 1 summarizes some of the features of the different atomic models that, according to us, are not in logical continuity and, therefore, don't refer to the same atom. For example, to go from classical atom to modern atom, it requires epistemological ruptures according to Bachelard's paradigm, because one doesn't pass from one atomic model to the other by a simple logical reasoning.

Table 1: The atomic doctrines

For the naive atomist (1)	**For the empirical atomist (2)**
- It is necessary to draw a particular attention to the process of division of matter, and to the wearing out of the hardest bodies. We believe it is all about visual inspiration approach. - The matter is a juxtaposition of atoms and the atom is a worn-out solid. - Matter is "hard", compact, and solid. - The atom, in this view, is an almost-palpable reality; it is about an iconic model of the "reality".	- The scientific reality is the measurement itself, much more that the object measured. - Don't make hypotheses, but stick to the experimental verifications. - The scientists tend to measure and then define (the instrument precedes the theory). - The atomic model is a useful analogy, and it has nothing to do with the "reality", which is sensory in nature.
For the classic atomist (3)	**For the modern atomist (4)**
- Everything can be explained by the extent and geometric shapes. - The advanced ideas are based on the classical vision of the world. - The elementary particles are "point masses"; similarly, the space is three-dimensional worldview, and the time is an isolated entity. - The scientists must have a geometric model of the" reality "; thus, the atom is a miniaturized model similar to the planetary system.	- The atomic theory is not based on sensory inspiration, because physics is guided by theoretical views where the phenomena are constructed theoretically (Zeeman effect, Stark effect, etc.). Thus, it is the doctrine that denies the clarity. - Observations are essentially made to test theoretical assumptions. - An elementary particle is an abstraction; its properties are defined while interacting with other systems only. - The atom is the symbol of a definition, not the symbol of a 'thing' embodied in a mathematical model.

Admittedly, this rupture is not always easy to understand at the conceptual level. It requires scientists to review their ideas so deeply in order to recognize the inadequacy of the concepts of the classical atom, such as explaining a phenomenon at the atomic scale. Similarly, to move from the classical view of atom to the modern view, it requires fluency in utilizing mathematical models, such as Fourier transformation and quantum statistical mechanics. These complex models are essential to the understanding and interpretation of phenomena at infinitely small scale (Heisenberg, 1962).

3 The interview protocol

Initially, we considered using an experimental set-up to interview the participants about their understanding of the atom, but we found this approach is technically not feasible. Therefore, we decided to conduct the interview directly with the teachers, because they are already familiar with the target concepts. Following is the interview questions and the justifications for each one.

Question # 1: In some physics or chemistry manuals, the atom is described by different models such as Thomson, Rutherford, de Broglie, Schrödinger, Heisenberg, Fermi-Dirac, etc. According to you, is it always about the same atom?

This question aims at clarifying whether teachers will refer to the same atom or to atomic models marked by different epistemological views. For example, a teacher may claim that the atomic models developed by Thomson, Rutherford, and Bohr are discontinuous (or represent different atoms). For instance, since Thomson knew that the electrons are negatively charged and the atoms are electrically neutral, he proposed a model of the atom as a sphere of positive particles in which an equal number of negative particles (i.e., electrons) are included to insure its stability. Nevertheless, in a later stage, experiments on radioactivity, conducted by Rutherford, have proved that Thomson's atomic model is inaccurate and does not coincide nicely with the results of experiences in radioactivity.

In the lights of these findings, Rutherford proposed a new planetary model of atom that adopted the basic principles of Newton's law of motion. From the latter perspective, the particles inside the atom (called "point mass") are under influence of mutually acted force that is similar to the force of gravity between any two masses. This model could not survive for long time because serious conflicts surfaced while trying to explain certain properties of matter. Scientists have quickly realized that classic electrodynamics is incapable to take into account the stability of Rutherford's atomic model, Bohr provided a solution to the dilemma using the quantum theory of black body radiation, proposed by Plank.

Question # 2: What is, for you, an atom? The goal of this question is to clarify teachers' understanding of the concept of atom. Indeed, the first question indicates teachers' thinking about the continuity or discontinuity of the epistemological views of atom, however it does not indicate how teachers conceive the representation of the atom exactly. For example, a teacher may ignore the underlying developments of atomic theories and claim that Thomson, Rutherford, and Bohr's atomic models do not describe the same atom; and yet, we would not be able to know his/her understanding of atom or which atom he/she is talking about.

Question # 3: Do you believe that the atom is real and exists in this world? This question refers to the existence of the atom in our real world "physical ", similar to the existence of any other "object" around us: Is the atom the symbol of a "thing" that we can see and touch like any other microscopic object? In fact, between 1980 and 1990 there has been a fast development of certain types of technologies such as optics, electronics, and computer programs. These technologies allow us to see and touch effectively an atomic object. But! How does it come? In the following passage, Haroche (2003) described a simple experimental device that allows us to see an atom:

> *When an object is placed under a microscope, each part of the object is capable of reflecting light (or photons) to our eyes. The information carried by the light (or photons) will be received by our eyes and then transmitted to the brain for processing. Then the brain would construct an image of the object. In case of seeing atoms, they can absorb light (or photons) from external sources, such as lasers, and be excited to higher energy levels. Subsequently, the excited atoms would release photons in all directions before falling back to the original ground states. With a suitable optical setup, the emitted photons can be detected by sensitive photodetectors (similar to human eyes). Then the atoms would appear in a photodetector like small bright spots. The diameter of each spot is determined by the light wavelength, and it is in the scale of micron (micrometer = 10^{-6}m). The size of the diameter is about ten thousand times larger than the actual size of the atom. Therefore, this optical observation doesn't describe the structure of atoms, but it does estimate their average positions. However, this observation is often sufficient to distinguish between individual atoms. (p. 94-95)*

Thus, when someone looks at the atom from the viewpoint of wave mechanics and quantum mechanics, one can claim that it is possible to see an atom, as described above by Haroche. On the other hand, it can also be claimed that the atom can't be actually seen according to the rational mechanics of concepts of mass, speed, and trajectory.

Accordingly, we can say that the words used in our ordinary language are inadequate or imprecise to describe the worlds at micro scale, as well pointed out by Heisenberg (1962) in the following passage:

> *The most difficult problem, however, concerning the use of the language arises in quantum theory. Here we have at first no simple guide for coralating the mathematical symbols with concepts of ordinary language; and the only thing we know from the start is the fact that our common concepts cannot be applied to the structure of the atoms.*

The purpose of interviewing teachers about this complex issue (the existence of atoms in the physical world) is the fact that we wanted to know if they are aware of the boundaries between the microscopic and macroscopic worlds. In this regard, we know that the objects around us are made up of atoms and molecules as well as atoms separately obey the laws of quantum physics.

4 Methodology

We conducted semi-structured interview sessions with eight secondary school teachers (N=8) and ten high school teachers (N=10). Each session lasted for thirty minutes. The participants were chosen on a voluntary basis. The participants are university science degree holders (Bachelor, Master, and Ph.D.) as well as teachers with professional certifications. The secondary school teachers have gone through teaching training (90 credits) longer than those of the collegiate (30 credits). For the latter, three teachers haven't gone through teacher training programs because it is not mandatory to do so before start teaching. Also note that, during the interviews, teachers answered the interview questions spontaneously, because they were not necessarily familiar with these types of questions. Moreover, other teachers were surprized by the nature of the questions posed during the interviews and the logic underlying these questions. These behaviours indicate that some teachers are not so familiar with the subject of this research.

5 Analysis

The analysis of the discourse of the teachers reveals the existence of representations relatively "naïve" of the atomic theories.

5.1 Analysis of question # 1

In some manuals of physics or chemistry, one treats the atom and one associates to it the names of Thomson, Rutherford, de Broglie, Schrödinger, Heisenberg, Fermi-Dirac, etc. According to you it is always about the same atom?

The subjects advanced by the teachers make us think that they are not conscious that the development of atomic theories is not continuous. Otherwise, the majority among them doesn't seem to have thought about the epistemological premises that underlie the various atomic models, hence their difficulty to elaborate a discourse on the different models. As illustration, here are some statements formulated by the participants:

> *"The notion of atom has changed with the studies of those scientists. One fundamentally looks for the same thing." (S1)*
>
> *"The perception that these people had at their time that makes them describing it in a different way." (S2)*
>
> *"It must have a given atom that is made of such way and that it is there. There is always a given universe, one had different models."(S4)*
>
> *"It is the same atom except that the men of science didn't see the same atom the same way" (S6)*
>
> *"It is always the same research... modified. It is a model that, it is always the main idea that is there, the idea of Democritus."(S8)*
>
> *"It is always the same atom I believe, but seen from a different perspective." (C1)*

"Of course, it is about the same atom, but from different views. In the end, it is linked to the discovery of what is thought to be the atom." (C2)

"Yes indeed, they will always speak about the same atom until they see it from a different angle." (C3)

For these teachers, the atomic models developed are not the same but nevertheless for them, it would always be about the same atom because this last would be part of a "universe" separated of knowing subject, hence its "immutability". For other topics, it is about the same model that is perfected more and more and therefore it is not at all about a paradigmatic change. Here it is how two teachers of the collegiate explain this development:

"The model of Thomson that was a kind of gelatinous substance, the atoms being as balls of gelatin touching themselves, whereas with the experiences of other time, he demonstrated that at that moment, he made a model with the atom while saying it must have a hard core with a surrounding space, that has been completed with the more recent theories, let's say with Bohr." (C4).

"When one speaks of the first models of the type of the model of Bohr, one considered the nucleus, the atom as being constituted of a rigid enough nucleus and an electron that revolve on a circular trajectory. But as the models improved, one changed, among others, about the electrons that turn around, well the theory evolved at that moment, from a certain phenomenon, one elaborates a certain model, a certain theory but as the years pass, one achieves that the model that one made itself doesn't correspond anymore to the reality. Then, at that moment, there is an evolution, one perfects the model." (C5)

5.2 Analysis of question # 2

None of the eighteen participants stated that it is no longer possible to imagine, after the theory of relativity and quantum mechanics, the atom as a symbol of something that has an 'intrinsic reality' independent from the observer. Like several well-known scientists and epistemologists (e.g., de Broglie, Schrödinger, Heisenberg, etc.), the modern atom is a symbol of a mathematical definition, simply because the theory that describes its structure is based on probability and uncertainty; which is an intellectual construct that allows us to understand the micro world.

Several teachers consider, implicitly or explicitly, the atom as being the symbol of a small 'thing'. This is how they expressed this idea.

"The atom is an elementary particle, which is the basic building block of matter. The matter is made up from stacking particles [that] are precisely indivisibles in to other smaller particles." (S2)

"The atom is the smallest particle of a substance [a particle is something] that makes it in one piece [for example] iron, the smallest piece of iron that one could have." (S5)

> *"The atom is the smallest part of matter." (S7)*
>
> *"Perhaps the atom is the smallest part, the smallest division of matter." (C2)*
>
> *"I believe, in a mass spectrometer, I can touch the atoms one by one. Therefore, I can assume that the matter is made up of these particles that are stacked one by one till they make few grams of matter." (C7)*
>
> *"The atom is the basic building block of matter. It is the smallest unit of matter." (C8)*
>
> *"The atom is a unit. An object." (C9)*

Three teachers implicitly seem to adopt an approach similar to that conceived by classical model of atom, because, and according to them:

> *"The atom consists of a nucleus and an electron or electrons orbiting around it at different radii." (C1)*
>
> *"I will assimilate the atom to a sphere, as described by Dalton. However, instead of seeing the electrons orbiting in a rigid sphere, I will see it as the probability of finding the electron at a certain distance from the nucleus." (C3)*
>
> *"[...] proton, nucleus, and electron move around." (C10)*

5.3 Analysis of question # 3

Regarding the existence of the atom in the reality, the majority of the teachers said: yes, it's true. Accordingly, we could categorize the responses into two types: (1) naïve, and (2) empirical.

> *"The law of definite proportions, law of analytic proportions [...] Lavoisier and so forth, it seems to me that it is sufficient to believe on the existence of the atom in the real world." (S7)*
>
> *"The atom should be there. The atom exists, it is absolutely something that exists, since we are there." (S4)*
>
> *"When we often hear about the splitting of atom and the power that comes out of it, then I think we should believe....it exists." (C1)*
>
> *"I believe in the scientific method, I believe in experimental science [...] so for me, the atom exists, it is obvious." (C2)*

6 Didactical impact and conclusions

According to the above considerations, we can conclude that physics and chemistry teachers have maintained relatively naïve representations of atomic theories. In this case, how can they address the issue of conceptual change and, hence, help students in understanding the concepts of atomic theories? It seems clearly that Justi and Gilbert (2000) and Niaz (2009) studies confirm that there is an urgent need to rethink about the training of teachers in order to include components that emphasizes the importance of science history and science epistemologies. There are many evidences that support this direction, starting with the expansion of what might be called the scientific culture (Riess, 2000).

However, it seems important to thus to underline that it is at this condition that teaches will have the opportunity to reflect on their own thinking, and conduct inquiries that may drive their awareness towards constructing better understanding of the topic; and hence generate possibilities of conceptual change. For example, the following question may arise: how science teachers can be provoked to change their epistemological assumptions on atomic theories, and who will provide them with opportunities to reflect on these assumptions? Given the complexity of this question, we will list a few answers to highlight the opportunities offered by this research in developing strategies that could facilitate teachers' self-reflections on atomic theories.

The first stage in our strategy is to make the participants think about the importance of social dimension of science (Niaz, 2009a). If a question is posed in this sense, it will allow the participants to view science as an avenue of social activities in which the search for reality or the truth occupies only a small space (Métioui and Trudel, 2013).

The second stage aims at studying the successive models of atom that have been developed during and after the development of the modern atomic theories. In this stage, teachers will be asked to specify the epistemological assumptions underlying the various atomic doctrines, while they are reconciled with social context (Justi and Gilbert, 2000).

According to this process, the modern atomic theory doesn't appear to be as a set of successive developments of the atom that is first described by Democritus.

Indeed, if a pre-service teacher lingers to clarify his/her epistemological and metaphysical premises (e.g., "God does not play dice" Einstein said), which underlay casual and probabilistic reasoning, he/she will understand why Bohr model does not represent a logical continuity with the Rutherford's planetary model. To this topic Niaz et al. (2002) underline the importance of the historic science to analyze the results of the experimentation that depend closely on the conceptual setting. Below, the authors illustrate the example of Thomson and Rutherford:

> *It is important that scientific progress be presented within a history and philosophy of science perspective. In the case of Rutherford's experiments it is important for students to understand that if most of the alpha particles would have deflected through large angles, then the atomic model presented in textbooks could not have been sustained. Furthermore, both Thomson and Rutherford obtained very similar experimental findings with respect to the deflection of alpha particles and yet their interpretations were different. In order to go beyond the positivist perspective (experimental findings/laws/theories) it is essential that students be provided a glimpse of scientific practice imbued with arguments, controversies, and competition between rival theories/explanations. (p. 523-524).*

This strategy would make teachers more critical when it comes to the uses of words like: observation, law, theory, verification, experimentation, proof, model, particle, wave, energy, space, time, speed, mass matter, etc. These words acquire meanings that are strongly associated with the epistemological context or paraphrasing of texts from science history book. For example, paraphrasing from Kuhn (a science historian) without paying meticulous attention to the context would result to confusion about the meanings of those words, as we have seen in this research.

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