PHYSICS' TEACHERS CONCEPTION ABOUT THE DEVELOPMENT OF THE MATTER CONCEPT DURING HISTORY

Abdeljalil MÉTIOUI
Université du Québec à Montréal, Canada

e-mail: metioui.abdeljalil@uqam.ca

Louis TRUDEL
Université d'Ottawa, Canada

e-mail: ltrudel@uottawa.ca

Abstract: In this article, we use a qualitative research method to reconstruct and analyze the representations of college physics teachers from Quebec in Canada on the concept of matter. We do this based on clinical interviews. This study shows that college teachers construct false representations since they often rely on naive epistemology.

Introduction

Many studies have focused on students' conceptual representation (from high school to university) on core concepts of physics (Hewson, 1982; Bagheri-Crosson and Venturini, 2006; Métioui and Levasseur, 2011). This research demonstrates that despite multi-year education many students have conceptual difficulties in solving non-canonical problems and moreover rely on false theories similar to the ones developed during history such as the theory of impetus in the case of the study of movement (Viennot, 2014). The present research follows this perspective and identifies the representations that college physics teachers from Quebec in Canada harbor on the concept of matter. It should be noted that theories on this concept constitute essential elements of knowledge in science curricula (from high school to university). In the first part, we will present a historical outline defining the conceptions that scientists make on the subject, from Greek antiquity until today, which will enable us to construct our protocol of interviews that we will use in the second part. Finally, we will describe the population studied and the general conclusions of our study.

HISTORICAL OVERVIEW OF THE CONCEPT OF MATTER

The history of science shows us that knowledge of the concept of matter was not scientific from the beginning. People were confronted with the idea of the matter by asking the question: where do the things that we see around us come from? For example, the Greeks have devised explanatory schemes based on the existence of particles of atoms that are eternal, stable and cannot break. For the philosophers, Leucippus and Democritus, we can translate all that exists from emptiness and moving atoms. Taking the ideas of his predecessors, Epicurus postulated that things are composed of fundamental "atoms" that unite or separate themselves, obeying natural laws (Thuillier, 1981).

The idea of elementary corpuscles rests on different theories. For example, Descartes (1596-1650) did not think that the elementary corpuscles were eternal. On the other hand, Newton (1643-1727) supposes them to be stable while admitting the action at a distance between masses, which has never been accepted by the Cartesians who considered actions between bodies were the result of collisions between them. But against this mechanistic trend, some scientists oppose an energy vision.

For the physicist Boscovich (1711-1787), atoms were not small balls, but rather mathematical points as centers of forces, a theoretical approach to the notion of the atom. For him, the prime elements of matter were entirely indivisible, and they were scattered in an immense void.

According to Thuillier (1981), the ideas of Boscovich were taken up again in the nineteenth century and this would have oriented the scientists towards the notion of energy instead of the notion of matter in the classical sense.

We already know from the discoveries of physicists Thomson, Rutherford, Bohr and others that an atom contains electrons located around a nucleus, itself composed of protons and neutrons. Similarly, it is known that the electron is bound to the nucleus by electromagnetic forces. On the other hand, in the nucleus, protons and neutrons are linked by a strong interaction force.

This historical reminder was intended to indicate the main stages in the development of the concept of matter. The richness of the models, as well as their conceptual and technical complexity, have not been entirely elucidated, but we can already think to a research whose results will allow the analysis of the discourse of physics teachers.

THE CONSTRUCTION OF THE INTERVIEW PROTOCOL

To uncover the representations of the teachers, we opted for a form of interview where we could interrogate the subjects directly. We present here the two questions selected for the interviews, as well as the reasons for these choices: (1) What matter is for you? And (2) Is there an ultimate constituent of matter?

According to the considerations of the first part, we can conclude, with the development of modern physics, that the concept of matter deviates more and more from the discourse maintained by scientists of the precedent era. This deviation has reached the point where scientists no longer speak of matter in the classical sense, but rather consider in term of the concept of energy since the advent of relativistic mechanics and quantum mechanics.

Our aim is to verify whether teachers are aware of the vague and ambiguous nature of this notion, contrary to the concept of energy that predicts accurate information about a given system (Wolter et al., 2002).

In quantum mechanics, the concept of energy gives information about the possibility of having an interaction between the states of a given system thanks to the equation "$H. \psi = E. \psi$". Similarly, within the framework of classical mechanics, this concept makes it possible to know the possibility of having "work" done on a given system using the equation $T + V = E$ (energy) where T is the kinetic energy of the system and V is its potential.

However, these concepts are not in logical continuity, in the sense of the historians of science Kuhn (1972) and Bachelard (1981), because, in classically mechanics, energy is defined along a trajectory, unlike Quantum mechanics where it describes a problem with eigenvalues.

As for the second question about the existence of an ultimate constituent of matter, we wanted to know if teachers were aware that scientists are no longer looking for an ultimate component that would be the basis of our material universe. On this subject, note that with the development of particle physics we know that matter is composed of two types of particles: leptons and quarks. Four types of fundamental interactions cause these elementary particles to interact.

The gravitational and electromagnetic forces at the macroscopic scale are well known; on the other hand, weak interactions and strong interactions are only observed at the nuclear level. This set of particles and interactions could, in principle, account for the entire hierarchy of the structures of matter, from atomic nuclei to stars and galaxies.

Note that nowadays, researchers are trying to find a single class of particles instead of the two ones above. Moreover, they also think that a single force could account for all the interactions between the elementary particles.

Method and Population

To identify the representations made by the teachers about matter, we conducted ten semi-directive interviews, each lasting about twenty minutes, on the above questions. The teachers' comments have been reproduced verbatim.

Each teacher has been identified with the symbol C_i (the ith teacher). Below is an analysis of the interviews conducted with ten teachers who participated in this research on a voluntary basis, nine of whom held a bachelor's degree (physics, chemistry, mechanical engineering and electrical engineering) and one held a master's degree in Physics (M.Sc.).

INTERPRETATION OF THE DATA OBTAINED IN THE TEACHERS' SPEECHES IN RELATION TO THE FIRST QUESTION

Concerning question 1, most teachers consider matter as a juxtaposition of atoms. It would be a concrete concept that can be apprehended by appealing to the senses. For example, subjects C_7 and C_8 have used "sensory" representations to define the matter. Here are the terms in which C_8 clarified his point of view about this concept:

"That is what makes the solid object on which one sits [...]. For me, matter is what one perceives daily, and that is what makes one exist [...] matter, that's it. It's solid; I touch it. For me, it's real." (C_7)
"That's all that surrounds us. Whether it is solid or gas or liquid, that is what I would call matter. That is what one can touch, that one can feel." (C_8)

Thus, this teacher has a naive conception of matter and grants a great confidence to his senses. In our view, this is a realistic approach that differs from the modern approach.

Subjects C_6 and C_{10} have specified in their answers that matter is made up of atoms. Thus, for these persons, the matter would be an assemblage of atoms. Here is how they clarified this idea:

"We can define matter from the atom, as we can define it from our environment. So, we can start from matter, so it's what surrounds us, to try to define what is the constituent of matter or even to go, to do the reverse. To say the matter is a collection of atoms which constitutes what surrounds us." (C_6)
"Matter and a set consisting of this raw material, in fact, which is the atom." (C_{10})

These two teachers have a naive representation, as they spontaneously trust the evidence of the first experience. It is the same for the teacher (C_3) who considers the matter as:

"All these particles (proton, ion, ...) there that form a rigid whole, a set if one wants [...]. A particle is a part of the matter." (C_3)

The explanations given by these teachers (C_3, C_6, and C_{10}) lead us to think that for them, the matter seems to be reduced to a set of combinations of atoms and that it is composed of fundamental particles, small elementary bodies. Moreover, none has insisted on the vagueness of the notion of matter.

However, two of the ten teachers interviewed (C_2 and C_9) attempted to define matter by referring to the energy concept but failed to provide a coherent explanation and asserted in their answers their difficulty in identifying the epistemological premises that underlie the concept of energy since they specify:

"It is energy ... it is what underlies all the transformations, all the revolutions, all the chemical physics reactions, all to, and then it is, of course, at the origin of life too ... but what it is, I do not know ... I think I prefer to say that I am not sure exactly." (C_2)
"It can be an assembly of these particles of atoms. If I consider it as a wave, I will say that it is energy, while being aware that energy is a notion that we understand very badly." (C_9)

For subjects C_2 and C_9, energy is a notion that is not well understood. In our view, on the contrary, it is a concept whose postulates are clearly established, as much in quantum mechanics as in classical mechanics. Indeed, in classical mechanics, one defines the energy of a physical system in motion as the scalar product of the resulting force exerted on the latter and its displacement. In quantum mechanics, energy is the solution of the equation with eigenvalues: $H. \psi = E. \psi$.

The answer given by the subject C_1 does not differ from those provided by the teachers C_3, C_6, and C_{10}. The latter, however, called for a quantitative assessment of the matter. For him, matter is a "quantity of the substance; this substance can be composed of several core elements." Moreover, the explanations given by the subject C_3 resembles those of the subject C_1, since according to him:

"Matter is a set of fundamental constituents arranged in different ways which cause the paper I have in front of me to be paper [...]. The matter is ultimately an assortment of primary constituents called protons, neutrons, and electrons, which are arranged in different ways in order and quantity, so that carbon, nickel is obtained." (C_5)

For this teacher, the matter seems reduced to a set of small elements since for him, the particles "are fundamental constituents which, from these elements, we reconstitute all the matter that we have around us." In our opinion, C_5 emphasizes the concept of a particle and does not seem to have grasped its high level of abstraction.

Finally, the subject C_4 explicates in his speech that everything that exists, in reality, is explained from the emptiness and the atoms. Indeed, in his words:

“Matter is all that surrounds us [...]. Matter for me essentially is made up of void. But within this void, there are grains [...]. The material consists of this grain, called the atom.” (C_4)

The above definition approaches the materialist thesis of the Greek thinkers Leucippus and Democritus that the origin of all things can be explained by primordial material elements (emptiness and atoms).

INTERPRETATION OF THE DATA CONTAINED IN TEACHERS' SPEECHES IN RELATION TO THE SECOND QUESTION

Regarding the question of the existence of an ultimate constituent of matter, none of the ten teachers interviewed stated in his speech that researchers are no longer looking for a final constituent of matter, as has been the case for several generations and that the actual research done in particle physics aims to understand the different types of interactions that govern the particles.

Subjects C_1, C_2, and C_{10} were not able to answer because they do not have a clear opinion on this issue. Moreover, teachers, C_4 and C_8 seem to assert in their speeches that the atom is the ultimate constituent of matter. For example, C_4 specifies that the atom is the fundamental element of matter:

“There is not one (the constituent of matter), there exists that whole which is at the basis of everything. We cannot say that the electron is the ultimate basis of matter, I cannot say that the proton is either. It is because I believe that in the matter, they are always encountered in the presence ... ultimately the ultimate basis is the atom which is the essential foundation.” (C_4)

In our view, the explanations given by this person about the matter and the existence of its ultimate constituent resemble those provided by the Greeks. Indeed, for him, matter is an assemblage of atoms, that is to say, of fundamental particles which are infinitely small.

The subject C_8 has specified in his speech that he prefers to speak not of the ultimate constituent, but of ultimate unity. Below is how C_8 explain his idea:

“The atom is a whole with what's in it like electrons, protons, all that. We cannot say that the electron is ultimate or that the proton is ultimate, the whole makes the atom. So far, ultimately, I would say the principal unit, it is the atom.” (C_8)

According to these remarks, C_8 seems to reason again at the level of the principal unit of matter which exists in the material world, a reasoning that no longer accords with the developments of modern science.

The answers given by C_5 and C_7 do not deviate implicitly from the answers given by C_4 and C8, namely a substantiate conception of matter. For example, C5 states that “possibly a fundamental constituent of matter will be found.”

For him, particles are essential constituents of matter that “they are primary parts which, from these elements, we reconstitute all the matter that we have around us.”

Moreover, C_7 does not seem to be aware of the preoccupations of particle physics, because “if in the universe one meets the atom of hydrogen, one also meets the free electrons and the protons and the nuclei. The universe is done the same way, I teach astronomy, astrophysics and then I do not see any problems more that.” In this representation, C_7 seems to concretize the concepts of the electron, proton, etc.

The teachers C_6 and C_9 referred to the notion of quark to interpret their answers:

“The current studies on the quark suggest that everything would build from that. Namely, we will find something else, smaller? Well, it is even imaginable. Easily believable.” (C6)

“If we rely on the historical evolution of knowledge, we may presume that when we have isolated the three quarks, we will decompose them into other parts.” (C_9)

The above comments lead us to believe that teachers C_6 and C_9 attach great importance to the problem of decomposition and show confidence in the existence of matter at the subatomic level.

Conclusion

From the preceding considerations, one can conclude that physics teachers have retained relatively naive representations about matter. Indeed, we have clarified that the explanations they provided follow the perspective of a philosophy of visual and sensorial inspiration. For most of them, matter consists of an assembly of particles. A result from a process of decomposition of matter. With such representations, one can understand why none of the respondents consider that the concept of matter becomes more and more abstract in the discourse of physicists, to the point where physicists prefer the idea of energy.

The results of this research on teachers' representations show that there is a need to rethink teacher training, if not to integrate into their training elements of history and epistemology of sciences (Niaz, 2002; Métioui et al., 2016). However, it is important to emphasize that it is at this condition that they will have the opportunity to reflect on their knowledge, to ask questions that lead to an awareness of the postulates that guide the construction of knowledge and generate conceptual change possibilities (Posner et al., 1982; Zhou, 2010).

For example, how can we induce an epistemological change in the teacher that will allow him to reflect on the epistemological breaks in the development of the concept of matter? Given the complexity of this question, we will just enumerate some answers to show that our research could allow the development of a strategy to facilitate teachers' assimilation of the concept of matter.

The first step is to make teachers think about the importance of the social dimension of science. A reflection begun in this direction will allow them to consider science as a human activity where the search for reality and truth occupies only a small place (Abd-El-Khalick and Lederman, 2000; Adúriz-Bravo, 2007).

The second step is to analyze the successive models developed during the development of theories on the composition of matter. In this stage, teachers will be asked to clarify the epistemological premises that underlie the different doctrines developed on the subject, while confronting them with their conceptions. According to this path, theories on the matter no longer appear to the teachers as the result of a serie of continuous improvements whose aim is the search for the ultimate constituent of matter.

Finally, it should be emphasized that such a teaching strategy will make it possible to see the conceptual difficulties encountered, for example, by scientists Thomson, Bohr and Rutherford, to name just a few, to develop their atomic models (Niaz et al., 2002; Métioui and Trudel, 2015).

References

Abd-El-Khalick, F., and Lederman, N. G. (2000). The influence of History of Science Courses on Students' Views of Nature of Science. *Journal of Research in Science Teaching*, 37 (10), 1057-1095.

Adúriz-Bravo, A. (2007). A proposal to teach the nature of science (NOS) to science teachers: The structuring theorotical fields' of NOS. *Review of Science, Mathematics and ICT Education*, 1 (2), 41-56.

Bachelard, G. (1981). *La philosophie du non (The Philosophy of No)*. Paris : Presse Universitaires de France.

Bagheri-Crosson., et Venturini, P. (2006). Analyse du raisonnement d'étudiants utilisant les concepts de base de l'électromagnétisme. *Didaskalia*, 28, 33-53.

Hewson, P. (1982). A case of conceptual change in special relativity: The influence of prior knowledge in learning. *European Journal of Science Education*, 4 (1), 61-78.

Kuhn, T. (1972). *La structure des révolutions scientifiques*. Paris : Flammarion.

Métioui, A., Matoussi, F., et Trudel, L. (2016). The Teaching of Photosynthesis in Secondary School: A History of the Science Approach. *Journal of Biological Education*, 50 (3), 275-289.

Métioui, A., & Trudel, L. (2015). Epistemological rupture in the discourse of high school teachers: The case of the atomic theories. LUMAT, 3 (4), 439-448.

Métioui, A., et Levasseur, J. (2011). Analyse des raisonnements d'élèves du collégial professionnel sur les circuits en courant continu et les lois de Kirchhoff. *RDST*, 3, 155-178.

Niaz, M., Aguilera, D., Muza, A. & Liendo, G. (2002). Arguments, Contradictions, Resistances, and Conceptual Change in Students' Understanding of Atomic Structure. *Science Education*, 86 (4), 505-525.

Posner, G., Strike, K., Hewson, P. and Gertzog, W. (1982). Accomodation of a Scientific Conception: Toward a Theory of Conceptual Change. *Science Education*, 66(2), 211-228.

Thuillier, P. (1981). L'approche scientifique de la matière (p. 12-29), In *La matière aujourd'hui*. Paris: Éditions du Seuil.

Viennot, L. (2014). *Reasoning in Physics: The Part of Common Sense*. Springer Netherlands.

Wolter, H. Kaper. and Martin, J. (2002). Forms of Energy, an intermediary language on the road to thermodynamics? Part I. International Journal of Science Education, 24 (1), 81-95.

Zhou, Z. (2010). Conceptual Change in Science: A Process of Argumentation. *Eurasia Journal of Mathematics, Science & Technology Education*, 6 (2), 101-110.