

Atomic models evolution in Mexican high school students



Virgen Huerta¹, Pilar Segarra², María de los Ángeles Ortiz²

¹Escuela Nacional Preparatoria 7, Universidad Nacional Autónoma de México.

²Facultad de Ciencias, Universidad Nacional Autónoma de México.

E-mail: vickyhr90@hotmail.com

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Abstract

The objective of this work is to show the importance of models in physics and a way to help the high school students to develop an atomic mental model accepted by the scientific community. The focus of the research is to look for a change from the students' inappropriate atomic model to the quantum model. We worked four years with (about 480) fifteen or sixteen year old high school students. An initial evaluation showed that they do not know the atom concept, their usual graphic representation is similar to the Bohr atom but with big mistakes. Through an educational itinerary the main atomic models are reviewed and analyzed through interesting traditional activities as well as ICT's, very well planned, and supported by group discussions and homework. The historical content has been interwoven and the main experiments associated with each model were introduced, including the quantum model. Obviously the mathematical formalism of the quantum model was not involved, however there was no problem discussing the process that took place with the actual atomic model with the students. In the final evaluation almost all the students recognize the importance of models in science, and the change and evolution of the models until the one accepted by the scientific community. The students change their language, but more importantly they change the graphic representation of the atom, from the planetary Bohr model with well-defined trajectories, to the orbital representation, *i.e.* the probability of finding an electron in some region. They accept and can describe the atomic quantum model as the one that explain all the known atomic phenomena.

Keywords: Atomic models, didactic transposition, high school physics, models in physics, history in physics teaching.

Resumen

Los objetivos de este trabajo son mostrar la utilidad de los modelos en física y una forma de ayudar a los alumnos a desarrollar un modelo mental del átomo acorde con el aceptado por la comunidad científica. La investigación se centra en determinar la posibilidad de que los alumnos migren del modelo con el que se suele identificar erróneamente al átomo, al modelo atómico cuántico. Se ha trabajado, en el curso de física introductoria durante cuatro años, con 480 alumnos de 15 a 17 años. Una evaluación diagnóstica mostró en todos los casos que los estudiantes no conocen el concepto del átomo y la representación gráfica (dibujos) que más utilizan es semejante a la de Bohr pero con errores graves. El tema de modelos atómicos se ha desarrollado por medio de actividades muy bien planeadas en tiempo y diversidad, apoyadas con discusiones grupales y trabajos en casa. La instrucción ha considerado brevemente el desarrollo histórico de cada modelo haciendo énfasis en los experimentos cruciales en la física, hasta llegar al modelo cuántico. No se presentó el formalismo matemático de la física cuántica, sin embargo, no hay problema en discutir con los alumnos el proceso que llevó al modelo atómico vigente. Las actividades realizadas son viables, accesibles y de gran interés para los estudiantes. En la evaluación final la mayoría de los alumnos reconocen qué es un modelo en la ciencia, la evolución del mismo y la importancia de que un nuevo modelo debe poder explicar lo que explicaba el anterior e incorporar nuevas explicaciones que el anterior no podía justificar. Los estudiantes cambian de lenguaje, el cambio principal se da en la representación del átomo, de dibujar el sistema planetario de Bohr con las trayectorias bien definidas por la de orbitales que representan la probabilidad de encontrar al electrón en una región del espacio, se percibe que los alumnos aceptan, nombran y pueden describir el modelo cuántico del átomo como el que explica todos los fenómenos atómicos que se conocen.

Palabras clave: Modelos atómicos, transposición didáctica, física de bachillerato, modelos en la física, historia en la enseñanza de la física.

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I. INTRODUCTION

Modern physics topics are not usually addressed in the courses of physics for all students at the Escuela Nacional Preparatoria, UNAM, although they are included in the last unit of the course. Apparently the difficulty falls on the conceptual problem that modern physics implies but surely the major problem is that most teachers do not know enough physics to teach these issues.

However, in the students' environment, terms related to the physics of the XXI century are frequently used related to modern technological devices, mobile phones, lasers, iPods, computers, diagnostic equipment, games, science fiction movies, etc. The work developed aims to provide junior high school students with the basic elements needed to venture into the sphere of atomic physics. This will help them understand the importance of quantum physics in the world in which we live, with enormous technological developments [1].

Research objectives are to show students the usefulness of models in physics and help them to develop a mental model of the atom according to the one accepted by the scientific community. The research focuses on determining the possibility for students to change from the planetary model of the atom which is commonly used in formal and informal education, to the quantum model proposed by the scientific community more than 80 years ago. This goal is against the common use of the Bohr model in traditional courses and in mass media, which can be easily represented in graphical form similar to the planetary model [2]. It is seldom noted that Bohr himself was convinced that his model was provisional and that it would be displaced by a new theory. Now we know that this theory was built in 1925 and explains the structure and behaviour of atoms since then.

Authors believe that high school students should know that many of the terms used nowadays have meaning in contemporary physics and have a basis in quantum physics. This paper seeks that high school students recognize that their technological world is based on quantum physics and in order to understand it, it is essential to know first its basis which can be introduced through the quantum atom.

II. THEORETICAL FRAMEWORK

Science is developed following two main paths. One is to gradually reduce the number of assumptions necessary to explain the results of observations or experiments; that is, proposing models and performing experiments that confirms or rejects them. Another method is through the discovery of unexpected events; often these findings are obtained during attempts to verify a model or theory. In this case, the existing models should be reviewed and changed, incorporating new findings into the structure of science. The involvement of both pathways is evident in the development of atomic physics.

A model in science is an imaginary and arbitrary way of representing the reality of an object or process; it is a

special and incomplete picture of a usually complex reality; in any model simplifications are always introduced. It is constructed to allow the study of a system in order to develop theories and laws that explain a more general context. Its goal is to help explain or understand a real system. Models may be presented through oral or written language, diagrams, geometrical or mathematical structures. A real system is not fully represented by any model. However, even in their simplicity they have been a fundamental means to develop science. During teaching it is essential to point out their limits of validity and the reasons and difficulties by which a new model is introduced to replace the previous one [3].

From an educational point of view, this study is within the constructivist paradigm where learning depends on prior knowledge of the pupil as well as the teaching approach which seeks to encourage individual reflection on the relationship of the new knowledge with the previous one [4]. We call mental models to those representations that each individual has in his mind. In Johnson-Laird's theory, mental models are considered partial, heuristic and in constant evolution, they can also be propositional or iconic [5, 6].

With the experience earned during four years of work on this theme and taking into account the description proposed by Johnson-Laird, it has become clear the importance of the use of models during teaching. The experience has shown us that individuals are able to migrate gradually from its initial model to a more scientific one. In the case of atomic models, drawings or simple diagrams have helped to introduce the concept of atom [7]. During the classes, it was made explicit the limitation of the first atomic models, as well as its evolution to resolve theoretical inconsistencies and to incorporate new experimental evidence. This focus helps to make students aware of the constant development of science.

Models have played an important role in the process of scientific thought and have allowed the explanation of a large number of phenomena in all areas [8]. Its use is so connected to our thinking that sometimes we are not aware of their employment and the difference between models and real systems. Therefore, in the training of students, it is necessary to value its application in physics and emphasize the historic evolution of models so that the explanations of a new model go beyond those provided by the previous one, as occurs in atomic models. For example J. J. Thomson discovered electrons through the discharge tubes and designed the plum pudding model for the atom. However, the model failed to explain Rutherford's experiment, being unable to explain the deviation of the alpha particles by the golden plate; so it was necessary to think up another model that postulates the existence of a tiny nucleus, positive and massive.

Our proposal is that students learn about the quantum atomic model through a historical development. Even though scientists know that Bohr's model is not correct, it is commonly used in mass media and books [9].

III. METHODOLOGY AND RESEARCH ANALYSIS

We have worked in the teaching of atomic models in the introductory physics course, with 2 groups of 60 high school students (15 to 17 years) for four years, with a total of 480 students. In each group the work began with a diagnostic evaluation in order to determine the students' previous ideas on the subject and build on them as the starting point. As in other studies, students' models were obtained through drawings and explanations [10, 11]. The diagnostic evaluation showed in all cases that students were unfamiliar with the concept of atom, mixing it with molecule, particle, cell or proton. The graphical representation used is often similar to that of Bohr's atom but with serious errors.

The issue of atomic models has been developed through well-planned activities, balanced in time and diversity [12]. Obviously, in order to produce a desirable educational strategy, it was necessary that the teacher knew the physics involved in theory and in experiments [13]. To select and use relevant activities, it was also essential to know the needs and difficulties of the students [14]. These activities are supported by group discussions and personal work. The historical development of the atomic models [15] emphasizing the crucial experiments that forced physicists to modify the previous model until they reach the quantum model, is considered briefly all the time. Criticism of each model helps to see their limits and justify the need for modifying it until one that explains all the atomic phenomena known was found.

The proposed activities are possible and accessible in real classroom conditions and are of great interest for most students [16]. Along with the experimental activities that are considered classics, we made use of modern technology through applets, simulations and videos, taking advantage of the belief that students are familiar with handling computers and movil phones. The subject is presented in an attractive way which is against the common notion that science is boring and impossible to understand.

During instruction, the atomic models of Thomson, Rutherford, Bohr and quantum are discussed briefly with the students. With the use of crucial experiments in physics, group work, homework, applets, simulations, blogs and web support, we showed how each of the models described in historical sequence explains some phenomena not explained by the previous one, to finally reach the current model. Despite the relative complexity of the models, everything helped the student to understand the phenomena better. Certainly there was no attempt to present the mathematical formalism of quantum physics; however, we found no problem in discussing with them the process that led to the current atomic model accepted by the scientific community.

IV. RESULTS

With the developed instructional design it was found that although it is certainly not appropriate to present the formalism of quantum physics at this level, there is no problem discussing with students the process that led since 1925 to the current atomic model. We have seen that the conceptual difficulty for students is the equivalent of the need to understand out-dated models of the atom. With this methodology, students accepted the atomic models in a significant and conscious way. They are not afraid that the models are abstract and they need not to see the atoms in order to understand the actual description.

In the work done by students on the final questionnaire, it can be clearly seen that the majority of them recognize what is a model in science, the importance of the evolution of models and the request for a new model to include what the previous one explained in addition to new results that the former could not justify. In these final questionnaires it is perceived that students accept, name and describe the quantum model of the atom as the one that explains all known atomic phenomena. This was a great gain because before the intervention they remembered, in the best cases, Bohr's model. It can be seen in the questionnaires, that they recognize different models of the atom, and may use the concepts such as charge cloud and probability to describe an atom.

The teaching path followed allowed students to accept new concepts, new ideas and new models without shocks, so we could get gently progress to the quantum model of the atom which was clearly accepted. In the final assessment they remembered different models and produced different images for each of them. It is remarkable that Rutherford's atom was drawn as a spiral as was predicted by classical physics that electrons moving around the nucleus would radiate and stick to the core.

Another important result is that students change their image of physics; they now know that its evolution did not end with Newton or Maxwell as is often thought by the emphasis in introductory courses [17]. With the historical narrative and anecdotes, students were able to realize that the history of science has not been easy. When someone proposes a new model or theoretical explanation for experimental results, in general the proposal is not accepted by the scientific community. However, after many discussions and parallel checking, it was made clear that science is not as cumulative and linear as may usually be concluded by textbooks [18]. The atomic models also helped to illustrate that physics is an evolving science in which people are working nowadays and where a new science is being built.

V. CONCLUSIONS

We think that the teaching of the quantum atomic model is the door that leads students to study quantum physics, because it introduces the language and point of view of the new physics. The problem of interaction between atoms to

Virgen Huerta, Pilar Segarra, María de los Ángeles Ortiz form molecules, solids, liquids, and everything we observe in nature may be addressed from it.

Although we are aware that it requires more time to say that the different models and its implications are dominated, we can say that the achievements obtained are sufficient for junior high school.

In this study we reach the same conclusion as Munch [19] when she suggests that teaching physics in high school must be done emphasizing the physical models, pointing out their simplifications and limitations.

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