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Literature Review

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First-Year Chemistry Students' Meta-Modeling Knowledge of The Line Spectra and The Bohr Model

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Abstract
The Bohr Hydrogen atomic model is an organized representation which is used to explain and predict the emission spectrum. The study explored the meta-modelling of first-year chemistry students. A purposive sampling technique was used to sample participants from the accessible population at a public university in South Africa. Two hundred and eighteen first-year Natural Sciences and Technology students formed the sample. A mixed-method explanatory sequential design involving (Questionnaire and Interviews) was adopted for this study. Data analysis combined a quantitative and qualitative methodology. The Kuhn cycle and Modelling competence were used as the theoretical framework. The findings indicated that the students' meta-modeling knowledge is limited. Furthermore, they struggled with identifying the type of models used in the Bohr model and emission spectra. Instructional implications recommend lecturers to design instruction guided by meta-modeling. Further studies are needed to determine another dimension of metamodeling meta-cognitivism.

Keywords: *Bohr Model, Meta-modeling, Contextual modeling, Modeling competence.*

Introduction

The atomic model has changed over time. For over two centuries, scientists have created different models of the atom. As scientists have learned more and more about atoms, the atomic model has changed. Modeling is a core practice of science with epistemological underpinnings in science education. Modeling is an ongoing process of developing, testing, refining, and improving models to explain phenomena (Gilbert, 2000). The atomic theory is a fundamental topic in chemistry that has philosophical, historical, and epistemological aspects. Modeling fosters students' epistemological knowledge of science and their ability to evaluate science. If students gain an understanding of scientific knowledge and how historical, philosophical, and technological contexts influence its development, they will be able to gain a more comprehensive understanding of science and, therefore, become more interested in science learning as a result.

The Bohr model is ubiquitous in high school chemistry across the globe (Kegan et al., 2008). In most countries, the quantum models are introduced at the university level. Numerous researchers (Taber, 2013; Tsaparlis & Papaphotis, 2009); Muniz et al., 2018) have reported that high school learners tended to retain ideas associated with the Bohr-type (planetary) models of the atom despite making some gains concerning quantum models. Dangur et al (2014) in a cross-sectional study among high school learners, undergraduate, and honors students reported that planetary models and the quantum model were blended to make hybrid models. The hybrid model consisted of the electrons moving around the orbits that use quantized energy levels. In a phenomenographic study involving second-year chemistry students Stefani and Tsaparlis (2009) interviewed the students on questions based on atomic orbitals, orbital theory, and the Schro¨dinger equation. They found that even students who performed the strongest in the interview held hybrid models of the atoms.

Meta-modeling knowledge (MMK) refers to the development of an understanding of the nature of models and an appreciation of the purpose of scientific modeling (Frotus et al., 2016). MMK is a bifurcation of the nature and purpose of models in science education. Meta-modeling involves defining models in terms of their representational, interpretive, and predictive powers. However, studies related to MMK and which are topic-specific on meta-modeling are rare in chemical education (Chiu & Lin, 2019). In South Africa quantum models of atoms are introduced at the university, there has not been much research on meta-modeling of the Bohr model. The concept of meta-modeling informs our understanding of how models and modeling work. Meta-modeling knowledge is knowledge about "how models are used, why they are used, and what their strengths and limitations are" Schwarz et al. (2009) (pp. 634–635).

Ke and Schwarz (2020) suggest that there are two types of meta-modeling contextualized and decontextualised. The first one can lead to epistemological knowledge and can be topic-specific. The latter is independent of the specific learning context. Krell et al., (2014) and Sikorski (2019) suggest that context-dependency of meta-modeling knowledge is of critical importance for assessing and teaching meta-modeling knowledge which should be further investigated in science education. The present study is context-dependent as it is topic-specific and focuses on the Bohr model and line emission spectra.

The difficulties students encounter with the transition from the Planetary model to the quantum model are legendary and several studies have shown these difficulties span across advanced chemistry courses (Muniz et al., 2018). In the present study, I argue that meta-modeling the Bohr model may improve the students' epistemological awareness about the nature and purpose of models. The history of atomic models over the last century provides an opportunity for students to be led through a complex web of reasoning about how new models are built and old models are discarded, based on a few simple observations. Science evolves circularly according to the Kuhn cycle from a historical perspective, much like the seasons of the year. The present study adopted a conceptual framework that consists of the Kuhn Cycle and a Modelling-competence framework (Nicolaou & Constantinou, 2014). The framework views modeling meta-knowledge to be an epistemological awareness about the nature and the purpose of models.

Numerous studies (Muniz et al., 2018; Greca & Freire, 2018) have reported that high school, undergraduate, and honors students' ideas on atomic models show that they have a tendency to make inappropriate associations and they fail to distill useful information from the models. Furthermore, students have strongly held conceptions about the behavior of electrons and atoms based on the planetary model which are stable and difficult to change. Many studies have been carried out on students' knowledge of quantum models, but comparatively little has been carried out to investigate how students navigate the meta-modeling of the Bohr model (Chiu and Lin, 2019). The research question of this study is to: Explore the MMK of the first-year chemistry students on the Bohr model and emission spectra.

Theoretical framework

The Kuhn cycle viewed the evolution of science from a historical perspective and was referred to as *The Structure of Scientific Revolutions* (Kuhn, 1962). In the structure, Kuhn argued that science was not just an accumulation of facts. Science is advanced by revolutionary explosions of new knowledge. Each explosion brings new ways of thought which are called new paradigms. A paradigm is a "universally recognized scientific achievement that, for a time, provides model problems and solutions for a community of researchers". The Kuhn cycle (Fig: 1) starts with the pre-science stage where no framework guides the scientific community. This can be the period of Democritus where the ontology of the atom took centre stage. The normal step involves a scientifically based model of understanding such as the Bohr model. The drift stage consists of an accumulation of anomalies, a phenomenon the model cannot explain. Model drift occurs when evidence about the phenomenon becomes excessive and the model breaks leading to a paradigm shift.

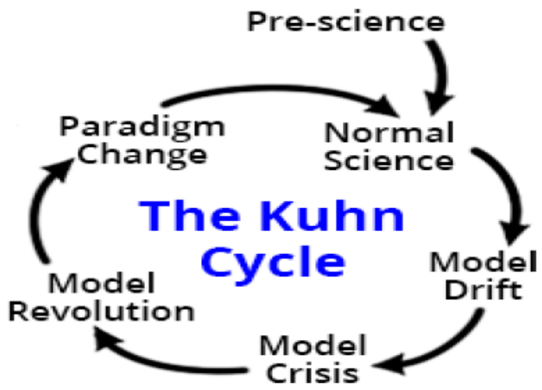

Figure 1: The Kuhn Cycle adapted from

The Modeling competence framework (Nicolaou & Constantinou, 2014) is fundamental to science education. The framework views modeling to be a dichotomy between Modeling practices and Modeling meta-knowledge. Modeling practices involve classroom practice where students are expected to create, use, validate, compare, and revise models. Modeling meta-knowledge consists of MMK and metacognitive knowledge of the modeling process. The present study focused on the Meta modeling knowledge that consists of the nature and purpose of models.

Models are abstract representations of a system of phenomena that explain and predict the central characteristics of the system. An appreciation of the purpose of scientific modeling and an understanding of the nature of models are called "meta-modeling knowledge". Meta-modeling knowledge about the nature of models entails a definition of models in terms of their representational, interpretive, and predictive powers. Scientific knowledge is a human construct and involves the process of modeling. Improving students' ability to think critically and integrate their conceptual knowledge by developing fruitful epistemological ideas is at the heart of meta-modeling.

Literature Review

Numerous researchers (Constantinou et al., 2019; Fortus et al., 2016; Chiu & Lin, 2019) have reported that although in inquiry-oriented science curricula, students may create scientific laws and models, neither they nor their teachers understand the nature and purpose of scientific models. In the present study, such knowledge is referred to as metamodeling knowledge. The argument is that if students struggle with MMK they cannot fully comprehend the nature of science, and their ability to use and develop scientific models will be impeded. Engaging students in meta-modeling has been shown to foster their epistemological knowledge of science, the nature of science, and their skill at evaluating scientific knowledge (Frotus et al, 2019).

According to Nicolau and Constantinou (2014), meta-modeling is the second branch of modeling competence. MMK is two-dimensional based on the understanding of the nature of models and an appreciation of the purpose of scientific models. The nature of models consists of the representational, interpretive, and predictive powers of the model. On the other hand, the purpose entails epistemic understanding. In science education engaging students in developing models is not enough to develop epistemological awareness of models and modeling (Constantinou et al., 2019).

The findings of educational research demonstrate that implicit instruction is not sufficient to develop the epistemological basis of scientific knowledge among students. Schwartz et al., (2012) suggest that there is a need for explicit epistemological discourse that prioritizes features of the epistemology of science in teaching and learning, and assessment. In a study involving three subjects Physics, Biology, and chemistry to find the relationship between metamodeling knowledge of models and modelling Gobert et al. (2011) found no significant relationship. A similar study explored the relationship between the relationship between students' views of scientific models and their ability to generate their models. The findings showed that few students who performed well in science and were motivated were able to develop coherent microscopic models. Based on the conflicting discourse on meta-modeling research on topic-specific such as the Bohr hydrogen atomic theory is limited in chemical education.

The topic of atomic models is anchored in the philosophy and history of science. The atom was first mooted 2500 years ago by Greek philosophers who introduced the concept of atoms as indivisible units that make up ordinary matter. The timeline of the atomic model showed that the model of atoms was continually improved and refined. The particulate nature of matter is a fundamental topic in science education (Treagust et al., 2010). Feynman et al., (2010, p. 2) described the topic as ' little imagination and thinking'. However, challenges with the atomic models have turned out to be a tremendous challenge in the classroom that spans from primary up to university level.

The historical approach as suggested by Weiner (2020) enables students to follow in the footsteps of philosophers and scientists and thus gain knowledge both about the epistemology and the process of scientific advancements. In an international study, 854 high school teachers were asked to draw atomic models. The findings reported showed that five common models: the Bohr model, the Rutherford model, the probability model, the orbital model, the probability orbit model, and the wave model. The modal model was the Bohr model. The question that has baffled researchers has been why students struggle with a topic that is anchored in philosophy and historical approaches. In the present, I argue that exploring meta-modeling might lead to understanding why students struggle to transition into quantum models.

Eilks (2015) cautioned teachers who followed the historical approach to avoid frequently mixing the models because it confuses the students. In the same vein, Gunnarsson et al. (2018) highlight that students' epistemological knowledge of different atomic models and the relationship between them is vital in chemical education. Research on meta-modelling that entails epistemological knowledge, nature and purpose of models on the Bohr model is still limited in science education. Tsaparlis and Papaphotis (2009) found that high school students tended to retain ideas associated with the planetary and Bohr-type models of the atom despite making some inroads concerning other models such as the probabilistic nature of electron behavior in atoms. Dangur et al., (2014) reported that even honours chemistry students retained the Bohr model and integrated the other models to form a hybrid model. The hybrid model is a blend of two models the planetary Bohr model where electrons orbit around the nucleus, and quantum mechanical assumptions with quantised energy.

Methodology

Context of Study First-year Chemistry

This study looked at the meta-modeling knowledge of the Bohr Model and Emission spectra. General chemistry is mainly done at the first-year level. In South Africa, the National Curriculum and Assessment Policy (CAPS) for Physical Sciences introduces the atomic structure at grade 10. Models of atoms require the students to state the key discovery in one sentence and match the discovery to the influence on the description of the atom. Furthermore, the students are expected to make a flow chart on the discoveries and construct a timeline. The topic is anchored on the history and philosophy of science which starts from the time of the Greek philosophers such as Democritus to the modern-day quantum model. At the first-year level, students are expected to transition from the Bohr model which is dominant in high school to the quantum model. Participants were drawn from two hundred and ninety-seven first-year Natural Science and Technology at a rural public comprehensive university in South Africa. A mixed method non-experimental approach which involved quantitative and qualitative analysis was adopted for this study. To address the principal research questions the present study used a questionnaire and interviews which were administered at the end of the semester. The questionnaire was developed along the definition of meta-modeling according to Constantinou et al., (2019). Meta-modeling knowledge is based on the nature of models and their purpose. The questionnaire (Appendix 1) had three questions based on Bohr's theory of the hydrogen atom. Question 1 (Fig 1) showed the model and the students were required to respond based on the nature of the model, its purpose, limitations, and modifications if possible.

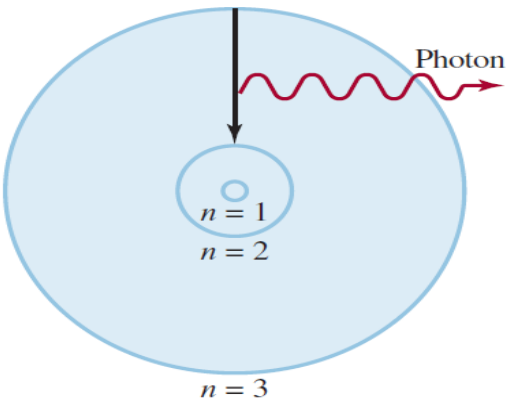

Figure 2: The emission process in an excited hydrogen atom, according to Bohr's theory adapted from Chang (2016).

The target population of this study was all first-year Natural Sciences and Technology Education in the Faculty of Education who enrolled at the beginning of the 2023 academic year at all twenty-three universities in South Africa. The accessible population was two hundred and eighteen (n = 218) first-year students at one public university in South Africa. An accessible population is a sub-population of the target population that is close enough to the researcher (Cohen et al., 2018). The ages of the participants ranged from 17 to 23 years. Two high school physical sciences teachers and two university lecturers checked the content validity of the questionnaire. Bohr's Hydrogen Theory Interview included questions relating to the two aspects of modeling. The interview included contextualized questions and pictures (Appendix 2) about the model. Semi-structured interviews, which took the form of a clinical interview occasionally asked the students to explain their responses. The 10 (five boys and five girls) interview participants were first-year Natural Science and Technology in the Faculty of Education. The students from the module volunteered and received the consent forms. Each interview lasted for 15 minutes. All participants and respondents provided informed consent and all research procedures complied with the UREC (University Research Ethics Committee) of the institution. For anonymity, students were randomly assigned pseudonyms. A pilot study (n = 30) was conducted in the second semester of 2022 to refine the questionnaire and interview questions before the implementation of the main study. Three questions on the questionnaire were rephrased. The study was not mandatory for any university courses or obligatory parts of the curriculum hence participation was voluntary.

All interviews were coded with NVivo software for data analysis. Students' responses were analysed using a data reduction technique to condense and capture the meaning of the responses. Afterward, a coding scheme to characterize and aggregate the students' responses was developed. The questionnaire had a rubric (Table 1) for assessment which was adapted from Constantinou et al., (2019).

Table 1: Rubric for assessment of meta-modeling adapted from Constantinou et al., (2019).

Level 4. The learner identifies the need for in-depth improvements with regards to one of the model utilities
Level 4.3. ….the model's representational power
Level 4.2. ….the model's interpretive power
Level 4.1. ….the model's predictive power
Level 3. The learner identifies that the model needs superficial representational and interpretive improvements
Level 2. The learner identifies that the model needs superficial representational improvements
Level 1. The learner identifies that the model needs unspecified improvements (which may result from their personal experience or from focusing on superficial features of the model)
Level 0. Irrelevant or no answer (The model is incomplete. No improvements are needed.)

The study was conducted at a public university in South Africa after the mid-break of the first semester. The researcher revised the lecture plans during the week of the semester break on teaching the atomic structure. The researcher prepared a lesson plan for each subtopic. Demonstrations and activities were revisited to match the target concepts. The researcher has more than seven years of teaching experience at the tertiary level, lecturing for first-year chemistry education. Natural science and Technology had a regular timetable of three one-hour long lecture periods per week and three hours for practical lessons. The subtopics of atomic structure were (a) classical physics to quantum theory, (b) photoelectric effect, (c) Bohr's theory of the hydrogen atom, (d) Dual nature of the electron, (e) Quantum mechanics. Guided by the theoretical framework involving Kuhn cycle and Modeling competence, the topic was taught emphasising the philosophical and historical approaches. The topic lasted for three weeks and was taught using a lecture-centered approach. The researcher avoided bias during the study. The dual role in a research study can lead to conflict of interest and bias. Kumar (2019, p.132), "Bias on the part of the researcher is unethical, bias is different from subjectivity. Bias is a deliberate attempt either to hide what you have found in your study or to highlight something disproportionately to its true existence". To avoid basis, the researcher did not in any way influence or change the findings of this study.

Findings

These are presented under the following subheadings: nature and purpose of the Bohr model and line emission spectra. Table 1 shows the distribution of response levels regarding the two aspects of meta-modeling knowledge assessed with the questionnaire. Across the six questions, the mean response levels range from 1.64 to 2.12. The overall mean level was 1.66 implying that the meta-modeling knowledge of the students was between levels 1 and 2. Question 1 required students to identify the name of the model, the modal level was 2 (The atomic spectrum of the Hydrogen Bohr Model). This shows that students had an understanding of the emission of the Hydrogen atom and Bohr's Theory. The purpose of the model revealed that level 1 participants thought of the quantisation of energy without providing the necessary background. While level 2 expressed that it was an emission spectrum. As far as the aim of the model was concerned, few students reached a more sophisticated level of understanding. This could be an indication that first-year students do not understand much about the purpose of the model.

The written responses on the extent to which the model is equivalent to their phenomenon showed that 50% of students thought it perfectly fitted the phenomenon. Based on theoretical approaches in the philosophy of science, scientific models are epistemic tools that are human constructs. Accordingly, modeling is an iterative and cyclic process that is aimed at predicting phenomena. When the Bohr model failed to explain the emission spectra of multi-electron atoms, elliptic orbits were proposed. Thus, in the present study students reflected a naïve understanding of models as copies of reality.

The purpose of the model was divided into three representations, interpretive and limitations. Representation had the lowest mean level response 1.64. More than half of the respondents could not identify the different types of models. Models can be represented as diagrams, pictures, and schematics. The findings of this study showed that students still struggle with model representations of the Bohr model. About 50% of the respondents identified the models as pictures. Thus students struggle with different types of models.

NATURE OF MODELS	**LEVEL 1**	**LEVEL 2**	**LEVEL 3**	**LEVEL 4**	**Level mean response**
1. What is the name of the model that describes the pictures above	Nature of light (58)	The atomic spectrum of Hydrogen Bohr Model (74)	Bohr's Theory of the Hydrogen Atom Emission Spectra (68)	Line Spectra and the Bohr Model (18)	**2.12 ± 0.17**
2. What was the aim of the model	Quantization of energy of light. (64)	Emission spectra (78)	Explain the Emission spectrum of the hydrogen atom (60)	Explain the line spectra of the Hydrogen after receiving a high-energy spark. (16)	**2.12 ± 0.13**
3. Explain the extent to which the model is equivalent to their phenomenon.	The model was equivalent to the phenomenon. (100)	No model is ever equivalent to the phenomenon. (68)	It fitted the Hydrogen atom only. For other atoms, it failed. (40)	A model approach to reality. The model didn't explain the phenomenon well except in the Hydrogen atom. The model correctly fits the quantized energy levels of the hydrogen atom. Only certain allowed circular orbits for the electron. (12)	**1.85 ± 0.18**
PURPOSE					
4. How the model works Representational	Pictures	Picture Schematic diagram	Picture, Schematic diagram, Orbit diagram, Analogy	An energy-level diagram for electronic transitions Orbit-transition diagram Picture & Schematic Diagram Analogy	**1.64 ± 0.02**
Interpretive	Electrons from the excited states release energy as they transition to the ground state. (108)	Discharge tube that is used to study emission spectra. Electrons release energy from higher to lower levels. (78)	Energy is emitted or absorbed by the electron only as the electron changes from one allowed energy state to another. This energy is emitted or absorbed as a photon that has energy. An electron has specific energy values in an atom (energy levels) (26)	An electron in an atom can change energy only by going from one energy level to another energy level. When a sample of hydrogen gas receives a high-energy spark. H-H molecules absorb energy. Excited to a higher level. Some of the H-H bonds are broken. They release excess energy by emitting light of various wavelengths. (4)	

6. What were the limitations of the model	Electrons do not move in circular orbits. (78)	It cannot explain multi-electron atoms. (70)	Mechanism of absorbing and releasing energy. (43)	Fails to explain the Zeemen Effect. How spectral line split in the presence of a magnetic field Stark effect (17)	**1.90 ± 0.03**

The interpretive question revealed varied responses from the respondents. Level 1 respondents mentioned that electrons release energy as they move from the excited to the ground state. While at level 4 (1.8%) of the respondents explained that electrons get an electric spark, and they absorb energy. The energy absorbed is then used to break some of the bonds. As electrons transit from the excited state to the lower state they release quantized energy as photons.

The written responses on the limitations of the model showed that some students answered the questions from a learning perspective. The mean response level was 1.91 which showed that most of the students had little understanding about the Bohr model limitations. A deep conceptual understanding was demonstrated in Level 4 where the students mentioned how the model fails to explain the Zeeman and Stark effect. The limitations seem to suggest that students rely on textbook examples as most students just noted that electrons do not move in orbits.

The interviews were used to obtain an in-depth understanding of the limitations and the revised models. The first theme was on the student's maintaining the Bohr and Rutherford models despite stating that electrons do not move in orbits or circular paths. The two models drawn are shown below:

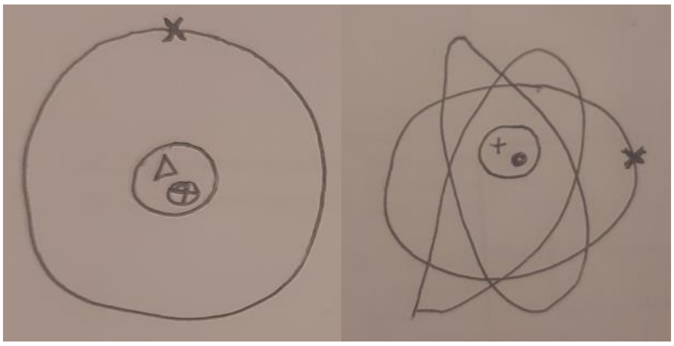

Figure 1.0: The Bohr and Rutherford Models

Interviewer: In your response to the questionnaire, you stated that one limitation of the Bohr Model is that electrons do not move in orbits and the revised model is still the same.

C: *I have always had grey areas with the atomic models. Though the model has some flaws it explains better the energy levels. It makes sense that transiting electrons lose energy as photons. In stoichiometry, it is the one that explains well the oxidation and reduction reactions. In HCl (H^+ & Cl^-) the atomic theory of Bohr makes a lot of sense. The wave model has too many calculations and is more difficult to relate than the planetary model.*

G: *The Rutherford model is the best because it shows the different orbitals where the electron can go into and lose energy. My main worry has been if electrons gain energy do they move horizontally or vertically? That's why I feel this model can be the best. After, all the atomic models are just approximations of reality*. *In chemistry that involves chemical reactions Rutherford's model is the best*.

From the responses, it can be deduced that students seem to suggest that the two models explain well the electron transitions between energy levels. There are areas of how the electrons gain and lose energy are still a problem among the students. However, in stoichiometry, the Bohr model is a good representation of when atoms lose or gain electrons (Lewis structures).

The students drew two other models: the probability and the wave model. Figure 1.2 shows the two models:

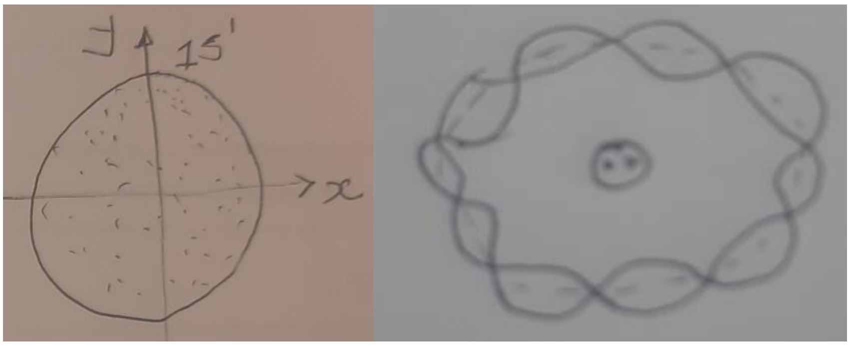

Figure 1.2: Probability and Wave Atomic Models

D: *Electrons do not move in orbits and the probability is the one I prefer because it fits well with the Heisenberg uncertainty principle. I am convinced that these are very small particles that behave in different ways. I struggle to relate cause it's a domain that I only imagine*.

F: *The wave model can be a better alternative. The dual nature of waves and particles is captured in this model. I just think principles that govern electrons can be compared to celestial bodies such as the planetary model. Calculus and abstract mathematics hinder my understanding*.

The two responses show that these alternative models capture the wave nature of electrons. Students agree that at the quantum level, the laws that govern celestial bodies cannot be used to explain phenomena.

Discussion

The present study explored the first-year chemistry meta-modeling knowledge of the Bohr Hydrogen atomic spectrum. The MMK was explored in two dimensions the nature and purpose of models. The topic of atomic structure is anchored in the History and Philosophy of science. In the present study, the MKK was topic-specific and contextualized. Similar to other studies (Krell et al., 2014; Sikorski. 2019), the first-year Natural science and technology students contextualized meta-modeling knowledge of the Bohr model seems to be rather limited. Most of the students could not identify the model in the questionnaire. It seems to suggest that students miss the point that Bohr's Hydrogen Atomic theory was proposed to interpret the line emission spectra. Almost half of the respondents agreed that Bohr's model fitted well with the phenomenon. Models are epistemic tools that are constantly tested by deducing and predicting the phenomenon. They are human constructs that approach reality and are never equivalent. The findings confirm that of (Torres & Vasconcelos, 2015) where half of the respondents reflected a naïve understanding of models as copies of reality. The nature of the Bohr Model showed that students struggled with the name, aim, and its equivalence to the phenomenon.

The purpose of the model required students to identify the type of representations used in the Bohr model. Many ways can be used to represent models which include, pictures, schematic diagrams, energy level diagrams, and mathematical formulae. The findings showed that level 1 respondents referred to the different diagrams as pictures. This might suggest that students do not understand the full spectrum of the models. The findings corroborate those of Valeeva et al., (2023) students struggle with different types of models which include physical objects such as diagrams or graphs; mathematical equations; computer simulations; analogies; and metaphors/stories.

The interpretive power of the model showed that students were familiar with electron transitions between energy levels. The process of how electrons get excited from the electrical spark was largely ignored by most students. However, most of the students linked the transitions to the quantization of energy as electrons occupy specific energy levels. The limitations of the model showed that most students relied on textbook examples such as it only accounts for Hydrogen and fails to predict multi-electron atoms. Only a few students managed to identify the Zeeman and Sark effect as a limitation of the Bohr model.

An interesting finding required students to draw a revised version of the model. The Bohr and Rutherford models were common. In-depth interviews showed that the models fit well in stoichiometry. This might explain why students cling to the hybrid models that include the planetary model. The results confirm that of Dangur et al., (2014) who reported that even honors chemistry students retained the Bohr model and integrated the other models to form hybrid models. This study has some limitations. First and foremost, two dimensions of meta-modeling were explored the epistemological awareness about the purpose and use of models. The third dimension metacognitive that involves the understanding of the actual modeling process was not explored. Lazenby et al., (2020) posit that there is no established form of assessment in chemical education research, which addresses metacognitive knowledge of the modeling process.

The findings indicate that pedagogical approaches to teaching the atomic structure need refinement on teaching models. Curriculum developers should use the MKK approach especially progression from one model to another. Using the MKK might focus on important aspects such as the nature, aim, and purpose of the model. Integrating history and philosophy based on MKK might help students to have a better view of models. Furthermore, students still have limited knowledge about models as human constructs which are constantly revised. The different types of model representation must be emphasized when teaching the Bohr model. Lastly, hybrid models that combine the planetary and wave models by students might be due to poor alternative models. The Bohr model works best in stoichiometry in chemical reactions.

Conclusion

To summarise, the current study contributes to the literature in two ways. Firstly, despite the whole topic of atomic structure being anchored in the history and philosophy of science the meta-modeling knowledge of the students on contextual meta-modeling remained limited. Furthermore, the students struggled to identify different models used to represent the Bohr atomic spectrum theory. Secondly, the students maintained the hybrid models because they could easily relate to them. The inherent structure of the discipline where Lewis structures seem to use planetary models during chemical reactions. The hybrid models are a result of the mathematical formalism in models after the Bohr model and hinder students' understanding. According to the Kuhn cycle, a paradigm shift occurs when new information sheds light on the existing model. This study has shown that a paradigm shift in students does not depend on new information only.

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