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Atomic Ontology in the Chemistry Curriculum and Implications for Optimizing Chemical Atomism in Teacher Education in Ethiopia

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ABSTRACT

This study is aimed at examining how the atom is ontologically presented in the curricular documents of teacher education in accordance with the persistence of the oldest notion of the atom and its corresponding ontological deviation. It involved content analysis of three curriculum frameworks and four modules through the interpretative coding approach of Merriam's qualitative case study. Accordingly, the curriculum was found to portray the outdated mechanical ontology as much as it endorses the targeted operational ontology. Even the operational ontology was found to controversially exhibit the mereological, functional and desired chemical notions. Though the narrative is more accurate in figurations of observable properties and phenomena, it is extremely problematic in its style and argumentation. Most of the arguments lack a solid foundation and the essential connections to the desired data, evidence, and contexts of those historical, philosophical, and scientific inquiries. This implies that issues of having an ontological basis, choice of words, and aligning corresponding components of argumentation with historical, philosophical, and scientific evidence and contexts must all be taken seriously for the curriculum to portray the targeted ontology and notion of chemical atomism.

Keywords: *atom; atomism; atomic ontology; chemical atomism; teacher education*

INTRODUCTION

What needs to be taught as a scientific truth or reality has remained so controversial throughout the history of science education. As a result, the essence of some topics was found to be so questionable that their omission from the science curriculum has strongly been claimed (Bensaude-Vincent & Simon, 2008). The atom and its theories are among the debatable topics of science in the history of chemistry and its education (Erduran, 2014; Taber, 2003). The most controversial and problematic aspect is its ontology (Bensaude-Vincent & Simon, 2008; Taber, 2003). Atomic ontology, in this sense, is concerned with the issue of whether an atom exists as a fundamental reality or not. Four principal categories of ontological views can be traced from the history of Chemistry and its education: *mechanical*, *hypothetical*, *interpretative*, and *operational* ontologies (Bensaude-Vincent & Simon, 2008; Jensen, 2010).

The *mechanical* view acknowledges atoms as physically or mechanically existing and perceptible objects of different nature. Such a corpuscular treatment of chemical phenomena has been found to be misleading in association with the persistent alternative conception of the atom as a materialistic core of matter that possesses color, odor, size, and other macroscopic properties (Gökdere & Çalik, 2010; Kind, 2004). The *hypothetical* view rejects the existence of an atom with different positions of the essence of the atom and atomic theories in the science curriculum. Some claim that the *chemists'* atom doesn't refer to any real particle of matter and, therefore, argue that atomic theories are not worth being learned while others philosophically reject the atom, but chemically support the inclusion of its issues as theoretical synthesis (Bensaude-Vincent & Simon, 2008; Jensen, 2010; Rocke, 1984). As a result, both the anti-atomism and agnostic atomism are accordingly shared within this ontological position. Anti-atomists don't agree with the existence of the atom and the essence of issues such as atomic theories in science education. Agnostic atomists prefer to avoid considering or thinking about the atom. They were historically known for deliberately neglecting those controversial issues of the atom and trying to explain the nature of matter and its phenomena in terms of variables such as energy (Bensaude-Vincent & Simon, 2008).

The *interpretative* ontology acknowledges the atom as an imaginary region, of the smallest chemical unit that can take part in a chemical reaction, in which those "experimentally discovered and verifiable" sub-atomic particles are found. It supports the inclusion of the atom not as an objective reality, but as a theoretical concept or model. The latest atomistic view such as *kinetic* and *electrical atomism* constituted it. *Operational* ontology asserts that something whose quantity can be, directly or indirectly, counted or determined does exist (Bensaude-Vincent & Simon, 2008). It is based on stoichiometric evidence from chemical analysis and employs scientific laws such as the Avogadro principle and the mole concept to compute and claim quantity and, thus, ontology of atoms in a given sample are based on the resulting values. Thus, it is also known as *stoichiometric* ontology (Bensaude-Vincent & Simon, 2008; Matthews, 2011). It is made up of two atomistic views: *functional* and *chemical* atomism. *Functional* atomism acknowledges the atom as the sole core of phenomenal relationships. Thus, it is criticized for the overemphasis of the atom. Chemical atomism claims an equivalent ontology for ions and molecules, especially in terms of fundamentality and natural existence (Taber, 2000).

The following are the principal assumptions of the targeted *chemical atomism* and its ontological basis, *operational realism*. They were adapted from the ontological meta-synthesis of Bensaude-Vincent and Simon's (2008) (*operational realism)* and Taber's (2003; 2000) 'benchmark' on the account of *chemical atom* and *ontology*.

1. A neutral system of a single nucleus with electrons is called an atom – the molecules of the noble gases are atoms.
2. A system of a single nucleus and electrons, which are only associated with that one nucleus, and which is charged (i.e., not neutral) is called a (simple) ion, and *whose constituent atoms do not discretely exist*. Many substances and their constituent atoms can also be widely found (or, exist) in the form of pairs of such ions.
3. The simplest molecules comprise a single or few more nuclei of the same atom, *whose constituent atoms do not discretely exist,* with one or more 'shells' of electrons, but only a small number of substances are considered to have the first structure (i.e., the monatomic molecules of the noble gases). Most molecules have two or more atomic cores shrouded by valence electrons.
4. The species under (1), (2), and (3) can't be *chemically* broken down further [into *chemically stable* and *discretely existing* smaller ones].

5. The species in (1), (2), and (3) *constitute* chemical substances in a repeating pattern, which in turn comprise the macroscopic world.
6. The number of species under (1), (2), and (3) in a given sample of a chemical substance or macroscopic world can be *determined* through the available analytical approaches, i.e., stoichiometric, gravimetric, and volumetric analysis.
7. The *existence* of the species can therefore be verified and confirmed *operationally*.

As a result, *operational* ontology must be targeted to optimize *chemical* atomism (Bensaude-Vincent & Simon, 2008; Matthews, 2011; Rocke, 1984). Conversely, *mechanical* atomism is out-of-date since an atom does not exist in such an objective sense. But the empirical literature shows that this notion was still found to be persistent within the diagnosed different senses of the atom (Erduran, 2014; Gökdere & Çalik, 2010; Taber, 2003). A cross-age study conducted on Turkish students' mental models of the atom reported that much of the representation manifests the outdated Democritus notion of mechanical ontology (Gökdere & Çalik, 2010). Similarly, a content analysis of general chemistry textbooks published in Turkey (1964-2006) conducted by Niaz and Coştu (2009) revealed that the books generally lack history and philosophy of science perspective. A meta-analysis, carried out in the UK's secondary and college education systems, also reported numerous inconsistencies and controversies within curricular philosophical foundations; teachers' epistemic and rhetoric competencies; prescribed and implemented entities (jargons, analogies, metaphors, examples, real materials, models, and illustrations) of the teaching-learning process. This analysis concludes that the curricular and pedagogical notions of the atom are oversimplified, outdated, and in deviation from the evidence and contexts of respective philosophical and scientific inquiries (Taber, 2003). Justi and Gilbert (2000) have also reported in their analysis of the curriculum for 14–16-year-olds using typical textbooks in Brazil and the UK revealed that the documents do not make appropriate use of historical models of the atom.

Such indications can be found in the curriculum of Ethiopia's secondary and undergraduate tertiary education. Misjudgment of Dalton's postulates of *chemical indivisibility* of the atom and *similarities of chemical properties of isotopes* in Grade 9 and Grade 11 textbooks, as well as the general Chemistry modules of primary teacher education, are among the examples of such indicators (MoE, 2010a; 2010b). Thus, this analysis aimed at examining how the atom is ontologically represented in the curricular documents of undergraduate chemistry [teacher] education to address the following basic questions.

Research Questions

a. How is the atom ontologically represented within the curriculum of science teacher education in Ethiopia?
b. How can the overall rhetoric pattern and desired associations be best maintained in terms of the reasons or origins of the implied ontological views to optimize the chemical atomism in teacher education?

METHODS

This study, in general, is concerned with the atom as a case of interest within the curriculum of teacher education. In particular, any piece or segment of the documents with an explicit or implicit implication of the ontology of the atom has been targeted. Drawing the ontological implications of the pieces of the data necessitates taking into account possible interpretations of the authors of the documents, researchers, and readers of the eventual report might make. As a result, Merriam's qualitative approach to content analysis was employed (Merriam, 2009). Accordingly, the data extraction and analysis involved the following stages of methodological cores of content analysis as per Stempel's (1981 as cited in Amare, 1998) suggestion for maintaining systematicity and rigor. The resulting data was extracted and registered on the data extraction and recording protocol prepared for this purpose of which a sample page is provided in Appendix A.

Determining Analytical Categories. Analytical categories were identified from the literature separately in association with the first and second research questions. The four ontological views or positions discussed under the introduction section (*mechanical, hypothetical, interpretative, and operational* ontology) are the categories used in relation to the first research question. Under the second research question, the four components of the *Dual Epistemic-Rhetoric* analytical model were used as analytical categories. These are *paradigm, style, figuration,* and *argumentation* (Ornatowski, 2007).

According to this model, the *paradigm* is concerned with views reflected on the reality of the issue under study by one's writing or talking. *Style*, as a component, is concerned with the syntax of sentences and the choice of words. It is more associated with language, for which it is also known as semantics (Lemke, 1990). *Figuration* refers to the symbolic aspect of one's expression or writing in which narrative and essayistic organization and use of visible tables, figures, and texts are examined. In terms of *argumentation*, the contents were examined in terms of the extent to which expressions, assertions, arguments, claims, interpretations, and justifications are supported by available experimental evidence and the context in which the experiment is planned and conducted (Ornatowski, 2007).

Establishing Units of Analysis. Specific courses substantially associated with the atom and its ontology were used as units of analysis. Thus, the courses were examined as units of analysis, both in terms of the frameworks and modules. Three curricular frameworks were obtained and examined. These were *the curriculum for Bachelor of Science (BSc) in Chemistry* (MoSHE, 2020), the *National Curriculum for Primary School Teachers for Generalist Environmental Science and Mathematics* (Grades 1–4) (MoE, 2014a), and the *National Curriculum for Primary School Teachers for Integrated Natural Science* (Grades 5–6) (MoE, 2014b). The first is being implemented for both the Applied Chemistry and Teacher Education programs since the consecutive modality has been employed for the secondary level.

Three courses were considered for the secondary level: *General Chemistry* (Chem 1012), *Inorganic Chemistry I* (Chem 2031), and *Quantum Chemistry* (Chem 4051). There are some more advanced courses in Analytical and Organic Chemistry. But they were disregarded as being substantial enough in incorporating the issue under study and maintaining fidelity. Besides, modules were prepared and distributed only for first-year courses; so, only one module of Chem 1012 was obtained. At the primary level, three courses were identified from the frameworks accordingly. These are *Basic Natural Science I* (BNSc 101), *Basic Chemistry* (Chem 201), and *General Chemistry I* (Chem 211). Course modules for primary teacher education are prepared and validated at regional level. This means that different modules have been prepared and used in different regions. As a result, modules of the last three courses were taken from Kotebe University of Education (KUE). It was a Metropolitan institution that prepare teachers for the capital city of the country, Addis Ababa.

Sampling of Contents. As this is a qualitative content analysis, the aforementioned courses as well as their chapters and contents were selected purposely as we had to focus on those with substantial notions and ontological implications. Hence, the sampling in this analysis is not randomized as asserted in the literature on quantitative content analysis.

Determining Criteria for Sorting Data into Analytic Categories. Three principal criteria for identifying and sorting data were formulated based on the targeted account of *chemical atomism.* The first is concerned with *acceptance* and *denial* of the atom as both a reality and a topic of science, while the second one involves the *notion* of the atom or *modes* of its implied existence (Appendix B).

Reliable Coding: Consistent Identification and Sorting of Segments. The identified chapters were read line-by-line first, by marking the portions found significant to the research questions. In the second round of reading, all such portions (symbols, figures, words, phrases, sentences, paragraphs) were recorded with their implied interpretations and atomic notions. This task of reading, identifying, and recording such significant pieces was carried out in the form of the *initial coding* of the grounded theory design. Then, the extracted data was re-examined to identify, label, and define major themes. This was followed by examining and sorting the initial codes into those major themes. This involved *focused* coding. Addressing the second research question involved two key tasks. The first is concerned with tracing and establishing major themes through which the overall rhetorical pattern of the documents is portrayed. Since these themes have not been known so far, an inductive coding approach was employed. The second is concerned with operational associations of those themes with the notions and models identified for the first two research questions. Generally, a coding guideline constituting the previously discussed categories, units, and criteria of analysis was developed and employed to maintain reliability (Appendix B).

RESULTS AND DISCUSSION

Overview of the Documents. Two types of curricular documents were located and accessed from all the desired sources. These are *the national undergraduate chemistry curricular frameworks* and *course modules*. The characteristics of these documents are briefly discussed as follows. Three curricular documents were found: the *Curriculum of Bachelor of Science (BSc) in Chemistry* that is being implemented for chemistry teacher education for secondary schools (MoSHE, 2020), *National Curriculum for Primary School Teachers for Generalist Environmental science and Mathematics (Grades 1 to 4)* (MoE, 2014a) and *National Curriculum for Primary School Teachers for Integrated Natural Science (Grades 5 and 6)* (MoE, 2014b).

The first was published in Microsoft Office Word format and distributed for public universities in 2020. It was drafted by three instructors from one of the public universities as a result of the launch of a new education roadmap, which unofficially kicked off in 2018 (Tirusew et al., 2018). According to this framework, the issue of the atom was found to be substantially discussed in three chemistry courses. The courses are General Chemistry (Chem 1012), Inorganic Chemistry I (Chem 2031), and Quantum Chemistry (Chem 4051). But, only module of the first course was obtained and evaluated (Yiheyis et al., 2019).

The last two frameworks were prepared, validated, and distributed to KUE and other regional colleges of teacher education (CTEs) for implementation in 2014 (MoE, 2014a; 2014b). According to these frameworks, the generalist program offers only one chemistry course (Chem 201) (MoE, 2014a) while the integrated science offers three chemistry courses (Chem 211, Chem 222, and Chem 323). The targeted issues of the atom are substantially discussed in Chem 211. Besides, both documents prescribed one more course called "*Basic Natural Science I*" (BNSc 101), in which biology, chemistry, and physics parts are incorporated. The Chemistry part constitutes three of the eight units. Modules of all these three courses were obtained and evaluated. These module were prepared and validated, are being used only at KUE. In addition to those aforementioned three frameworks, the following four modules were analyzed (Table 1).

Table 1: Courses, chapters, and contents analyzed in the study

No	Course Name and Code	Credit Hour	Program; Year/Semester	Selected Chapters	Title of the Chapter
1	Basic Natural Science I (BNSc 101)	1/3	Diploma/ESM[1]; IS[2] I/I	4	The Atomic Theories of Matter and Electronic Structure of Atom
				5	Chemical Bonding, Intermolecular Forces and Stoichiometry of Chemical Reaction
2	Basic Chemistry (Chem 201)	4	Diploma/ESM II/I	2	Matter and Energy
				3	The Atomic Theories of Matter
				4	The Electronic Structure of Atom
				5	Periodic Classifications of Elements
				6	Chemical Bonding
				7	Chemical Formula, Equation and Stoichiometry
				9	Solutions
3	General Chemistry I (Chem 211)	3	Diploma/IS II/I	2	Matter and Energy
				3	The Atomic Theories of Matter
				4	The Electronic Structure of Atom
				5	Periodic Classifications of Elements
				6	Chemical Bonding
				7	Chemical Formula, Equation and Stoichiometry
4	General Chemistry (Chem 1012)	3	Degree I/I	2	Atoms, Molecules, and Ions
				3	Composition of Substances and Solutions
				4	Stoichiometry of Chemical Reaction
				5	Electronic Structure and Periodic Properties of Elements
				6	Chemical Bonding and Molecular Geometry
				8	Organic Chemistry

[1] Environmental Science and Mathematics (for Grade 1 to 4)
[2] Integrated Science (for Grade 5 and 6)

The Chem 1012 module was prepared by three instructors from *Haramaya, Wachemo,* and *Mizan-tepi Universities*. In 2020, it was published in PDF format and has been used by all public universities offering the program. It can also be realized that it was MoSHE that facilitated, moderated, and financed the preparation sessions held at Bishoftu town. However, the document neither explicitly nor implicitly gives any information about how, when, and by whom it was reviewed and validated. There is also no indication of its authenticity except that the name of the ministry, authors, and their affiliations are only printed on the cover page. The remaining modules were prepared in the form of *handouts* at the University and published in PDF form in 2015. There is no clear indication of how, by whom, and when the preparation and validation were conducted.

Implied Ontological Views. Two major themes of ontological views were found from the analyses. These are the desired *operational* and outdated *mechanical* ontologies.

The Operational Ontology. This is the major theme of the ontological view of the atom that the curricular documents portray. The documents were found to acknowledge the atom as an *independently-existing* and *chemically-fundamental constituent* of substances. It is substantially manifested in the rhetoric of all the examined documents and their chapters. It is, for example, one of the *only* two views manifested in the rhetoric of all the examined chapters of the Chem 1012 module. It also constituted much of the rhetoric of *stoichiometry, electronic structure of matter, periodic classification of elements,* and *organic chemistry* topics of all the examined modules (Chem 1012, Chem 211, Chem 201, and BNSc 101). Besides, it has a substantial place in the rhetoric of substance *composition* and corresponding quantitative aspects.

This is the much desired ontological view that needs to be part of one's science education to optimize chemical atomism. But, not all of the segments of the data in this category fit into this very ontological realm and the prescribed notion of the atom. Because an inevitable proportion of the data, which was identified and sorted under this *operational* major theme of implied ontology, depicts the atom as the *sole constituent* and *fundamental unit* of chemical analysis with either a *mereological* or *solely-emphasized* atomic notion. Thus, only the remaining proportion belongs to the targeted *chemical* notion. The three atomic notions are discussed as follows.

The Mereological Notion. Mereology is the study of the relationships between parts and parts within a whole. It is believed in this theoretical sense that an atom does not lose every shred of its identity when it combines with other atoms or a group of atoms to form compounds (Newman, 2016; Scerri, 2007). This is the other notion of the atom that appeared to be boldly portrayed by the rhetoric of all the documents. In particular, it was found to be dominantly manifested within the rhetoric of chapters and their topics of *classification of substances, composition of substances and solutions, stoichiometry of chemical reaction, chemical bonding,* and *organic chemistry* of the modules (Chem 1012, Chem 211, Chem 201, and BNSc 101). The majority of the segments of this sub-theme are associated with *linguistic* components of the analytical model with a specific typology of *choice of words*. Only a few were found to be associated with the *figuration* component. There are also a few more segments associated with both the *style* and *figuration* components of the analytic model.

Linguistically, the choice of words was found to be severely problematic. It seems that the authors were not concerned with the type and possible implications of words. Words such as 'contain', 'contains', or 'containing' were used frequently in mereological connotation. Such uses of *"contains"* or "*containing"* are so problematic when used within the context of *chemical formula, the mole concept, percentage composition, properties,* and *structure,* to refer to compounds. This is to mean that such use of the terms in the case of mixtures in general and solutions, in particular, wouldn't be problematic. The following excerpt from chapter three of the General Chemistry module (Chem 1012 module, 99) illustrates this very well. It is concerned with the composition percentage of compounds such as ammonia and urea.

> *As one example, consider the common nitrogen-containing fertilizers ammonia (NH_3), ammonium nitrate (NH_4NO_3), and urea (CH_4N_2O) … A molecule of NH_3* ***contains*** *one* ***N atom*** *weighing 14.01 amu and three* ***H atoms*** *weighing a total of (3 × 1.008 amu) = 3.024 amu.*

Not to forget that there are no such things in *nature* as *N-atoms* or *H-atoms. The* quoted expression implies that nitrogen and hydrogen *atoms* retain their atomistic properties and, therefore, exist in compounds such as ammonia and urea. This sounds as if the identity of constituent elements before (in a discrete atomistic or molecular state) and after (in a compound state) the formation of their compounds remains the same. Such use of "*contain (s)"* or "*containing"* therefore has such a *mereological* connotation in that it prescribes the *billiard ball* notion of the atom that can't be changed during a chemical reaction.

The Solely-emphasized Atomic Notion. This is a notion that acknowledges the atom as the sole constituent of matter. The good thing is that it bears a partial alignment with available evidence as well as the desired historical and philosophical contexts. According to this functional view, the atom is therefore considered as an independently-existing and chemically-indivisible sole constituent of substances in the world whose ontology can be verified through stoichiometric analysis of actions and relationships observed in those chemical phenomena. The alignment, however, is not that complete in that such a notion of the atom appears to neglect the status of simple ions and molecules as both independently-existing and chemically-indivisible constituents of substances.

Not much was found concerning *style*. The significant segments identified and sorted under this ontological theme are of two types. The first one is concerned both with the choice of words and their syntax. For example, the last sentence in the following excerpt from the second unit of the General Chemistry module (Chem 1012, 51) implies that *ions* are just other forms of *atoms*. This gives autonomy to *atoms* in terms of being both *independently-existing* (ontology) and *chemically-fundamental* constituents (*fundamentality*).

> *Iodine is an essential trace element in our diet; it is needed to produce thyroid hormone. Insufficient iodine in the diet can lead to the development of a goiter, an enlargement of the thyroid gland (Figure 2.2).* ***The iodine atoms*** *are* ***added as anions****, and each has a* 1^- *charge and a mass number of 127.*

The second one is associated with *syntax* only. It is related to not just the *style* component, but the *figuration* component too. Because the sentence refers to the symbolic illustrations that precedes it. The following is a typical caption of a figure from unit two of the same module (Chem 1012, 53).

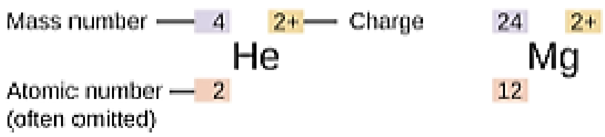

Figure 1: Symbolic illustration

> ***The symbol for an atom indicates the element via its usual two-letter symbol****, the mass number as a left superscript, the atomic number as a left subscript (sometimes omitted), and* ***the charge as a right superscript****.*

It appears that the subject in the sentence is a *symbol* [of an atom]. The next phrases seem to refer to and define this subject. Under such circumstances, the last phrase does semantically indicate that an *atom* could have a charge. This makes the style in this sentence sound as if the *atom* is the only *chemically-fundamental* and *ontological autonomous* species, undermining or ignoring the chemical fundamentality of the ion and its ontology.

Concerning *figuration, e*xplanations provided on the *composition of pure substances* and *solutions, the stoichiometry of chemical reactions,* and *organic chemistry* were found to be so problematic. *Atomic*, *molecular,* and *formula mass* are the sub-topics in which such expressions are dominantly used. Expressions of this sort were also dominantly employed within the rhetoric of other sub-topics of the chapter, such as the *mole concept* and *percentage composition*. The point in the following excerpt, for example, is that it attempts to explain the composition of *water* and *hydrogen peroxide molecules* in terms of *hydrogen* and *oxygen atoms*. But hydrogen and oxygen do not exist in the form of an *atom* in their uncombined state nor in their molecular compounds.

> *For example, water,* H_2O*, and hydrogen peroxide,* H_2O_2*, are alike in that their respective* ***molecules*** *are composed of* ***hydrogen*** *and* ***oxygen atoms****. However, because a hydrogen peroxide* ***molecule*** *contains two* ***oxygen atoms****, as opposed to the water* ***molecule****, which*

has only one, the two substances exhibit very different properties. Today, sophisticated instruments allow the direct measurement of these defining microscopic.

[Chem 1012, 91]

Thus, rhetoric forms of this sort are misused to explain the composition of compounds in terms of species that have never existed. The composition could have been explained in terms of simple, diatomic, and discrete molecules. Such figurations, therefore, neglect the desired status of the *molecule* and overemphasize the *atom*. In similar ways, the word *atom* was misused instead of *ion* in several more figurations of topics such as *chemical reaction, equation, reactivity,* and *type of reactions*. The following is a quote of a typical explanation from chapter four of the General Chemistry module (Chem 1012, 144).

*… The iron half-reaction is already balanced, but the chromium half-reaction shows two **Cr atoms** on the left and one **Cr atom** on the right. Changing the coefficient on the right side of the equation to 2 achieves balance with regard to **Cr atoms** …*

$Fe^{2+} \rightarrow Fe^{3+}$

$Cr_2O_7^{2-} \rightarrow 2Cr^{3+}$

*The iron half-reaction does not contain **O atoms**. The chromium half-reaction shows seven **O atoms** on the left and one on the right, so seven water molecules are added to the right side …*

As can be easily figured out from the half equations, all the species are polyatomic *ions*. The entities constituting the polyatomic *ions* are also *ions.* They are therefore not neutral. Thus, they are not *atoms*. The entire elaboration of example 4.7, however, was found to frequently address these entities as *atoms*. The *ions* are addressed as *atoms* more than five times throughout the solution part of this example. Generally, at least ten and six similar cases were identified, respectively, in chapters four and eight of the General Chemistry module. Discussion and computation of the constructs of all the aforementioned cases were carried out in terms of that of the atom. Because the figuration of this form potentially implies the "*everything is made of atoms*" notion, it overemphasizes the atom even though *ions* and *molecules* can be equivalently *fundamental* and *independently-existing*.

Argumentations of this form are few. The message they portray could, however, be very powerful and strongly contagious. There are of two types: those which refer to atoms that never existed, and failure to and gaps in linking those claims, expressions, justifications, and inferences with available experimental evidence of stoichiometric, volumetric, and gravimetric analysis. The rhetoric of the first form is rare in frequency. It was found to be employed within the discussion of a few sub-topics of chapter three of the Chem 1012 module: isotopes, chemical symbols, and formulas, of which the following is very typical.

*The expression **2H**, on the other hand, indicates two separate hydrogen atoms that are not combined as a unit. The expression $2H_2$ represents two molecules of diatomic hydrogen.*

[Chem 1012, 57]

In an attempt at justification and further illustration, the fundamentality of the atom is precisely addressed in such cases of molecules; but there is still a problem with the existence of the constituent-atoms such as H and O. Because in the real world, there are no such things as H and

O *atoms* since both hydrogen and oxygen have never existed in the form of an atom. They exist in discrete diatomic molecular form (H_2 and O_2) or ions (O^{2-}, H^-, or H^+).

Two key problems were observed within the rhetorical forms of the second case. In some of the interpretations, justifications, and inferences, it was attempted to rely on available experimental evidence of stoichiometric, volumetric, and gravimetric analysis. But such attempts were found to be not to the desired level of coherence as the desired links in the historical, philosophical, and scientific contexts were not maintained. The following quote from the Basic Chemistry (Chem 201, 96) module, for instance, shows how the atom is solely used (overemphasized) in such stoichiometric interpretations, justifications, and inferences.

> *The chemical equation described in section 4.1 is balanced, meaning that equal numbers of atoms for each element involved in the reaction are represented on the reactant and product sides.*

This conservation is only possible because some independently-existing and chemically-fundamental constituents of substances and chemical reactions do exist. It would have been preferable if the authors first established clear philosophical and scientific foundations for how the basic laws of chemistry work and then supported their claims with available experimental evidence of stoichiometric, volumetric, and gravimetric analysis in such a way that such laws are proven to hold only in the presence of chemically fundamental and indivisible, independently existing atoms, ions, and molecules. The argumentation in this quote therefore potentially implies the "*everything is made of atoms*" notion – it overemphasizes the *atom* as if a) it is only the atom that reacts to form substance, and b) it is clear and verifiable that it is only the *atom* that fundamentally existed in the world. This could potentially endorse an atomistic view that acknowledges only the *atom* as a *discretely-existing sole constituent* of matter. Similar overemphasized *arguments* were found in the different sections of the other modules (BNSc 101, 37; 38; 40; 41; 42; 46; Chem 211, 138; 142; 143; 147; 148; Chem 1012, 53; 56; 58; 60; 61; 66; 67; 68; 74; 78; 88; 89; 90; 91; 120 - 126; 144; 205; 320; 334; 338; 339)

On the other hand, interpretations, justifications, and inferences of other forms were found to be against available evidence of quantum mechanics and/or stoichiometric analysis.

> *This [Figure 2.7] identifies the elements titanium (Ti) and oxygen (O) as the constituents of titanium dioxide, and indicates the presence of twice as many* ***atoms*** *of the element oxygen as* ***atoms*** *of the element titanium …*
>
> *… A crystal of titanium dioxide, TiO_2, contains titanium and oxygen in a ratio of 1 to 2.*
>
> [Chem 1012, 59]

The rhetoric is precise in terms of the aforementioned structure and the macroscopic identity of the constituents. The microscopic constituents, however, are not really atoms. As TiO_2 is an ionic compound, titanium doesn't retain its discrete atomic properties. Neither does oxygen. The compound is composed of the respective ions that attract and hold each other. So, titanium and oxygen atoms are not found in TiO_2. The rhetoric of this form, therefore, contradicts evidence of x-ray diffraction, spectroscopic, and potentiometric analyses.

The Chemical Notion. This is the more desired notion of an atom, informed by the conceptual account of the research as well as available evidence and observations of stoichiometry, gravimetric and volumetric analyses, and classical and quantum mechanics. It is, of course, interesting that this notion appears substantially in the examined curricular documents. In the Chem 1012 module alone, it was found to be substantially implied by the rhetoric of chapter three and unavoidably significant in chapters two and four. No indication of its implications was, however, found in chapters five and eight. It is found in all the forms of the analytic model except that of the first *paradigm*. Figuration was found to be the component that appears bold in those aforementioned chapters. The following sub-sections, therefore, discuss the linguistic, figurative, and argumentative aspects of the documents that fall under this notion of atomism.

Concerning *style, a* comparable proportion of the identified segments are simple, accurate, and appropriate for the issue for which they were selected. Besides, the use of jargon and homonyms is so minimal in the rhetoric pieces of this form. The words couldn't portray other meanings than the issue they meant to. *Atoms, ions, molecules, discrete, composed of* (for cases of pure substances), *"contains (s)", "containing", "consist (s)"* and *"consisting"* (for cases of mixtures) are among the common words and phrases, which are more precisely and accurately used to mean what they need to mean. Among such desired cases is the title of Unit 2 from the very beginning. Those three words portray a very accurate style that, from the very title—"*Atoms, Molecules, and Ions*"—acknowledges *atoms, ions,* and *molecules'* fundamentality and independent existence as chemical constituents (Chem 1012, 47). The same words were also used as the title of the last sub-topic (4.3) of the last unit (unit 4) that deals with the chemical constituents of matter in the Basic Natural Science I module (BNSc 101, 15).

Many more excerpts can be quoted with the accurate selection and use of words, such as "*composed of*" as a better alternative to omitting "*contain (s)", "containing", "consist (s)",* or *"consisting"*. The following can be a typical example: The term "*composed of*" is better and more accurate for such cases of compounds than that of "contain". However, it can easily be figured out that it was picked unintentionally since the word "*contain"* was found to be still used in the same quote.

> *Analysis of a 12.04g sample of a liquid compound* ***composed of*** *carbon, hydrogen, and nitrogen showed it to* ***contain (?)*** *7.34 g C, 1.85 g H, and 2.85 g N. What is the percent composition of this compound?*

[Chem 1012, 99]

There are other equivalent parts where "*contain", "contains", "containing", "consist", "consists"* and *"consisting"* are used in a rather accurate form and context. The following is one such form: The use of containment for such a mixture is a more accurate rhetorical description of species formed physically.

> *A 5.0 g sample of spinal fluid* ***contains*** *3.75 mg (0.00375 g) of glucose. What is the percent by mass of glucose in spinal fluid?*
>
> *[**Solution**]*
>
> *The spinal fluid sample* ***contains*** *roughly 4 mg of glucose in 5000 mg of fluid, so the mass fraction of glucose should be a bit less than one part in 1000, or about 0.1%. Substituting the given masses into the equation defining mass percentage yields*

[Chem 1012, 111]

The *figurations* of these sub-themes of atomic notions were found to be one of the major themes of the overall rhetorical pattern of the documents. In general, the documents are good in their symbolic, chemical, and linguistic figurations of observable and simple scientific facts and evidence. It was found within these figurative forms that due accuracy and precision were demonstrated through the selection and use of appropriate symbolic, linguistic, and chemical figurations. Such figurations are characterized by either of the following categories: On the one hand, *specific* rhetorical entities were used for entities and phenomena of known identity and property, while *generic* ones were, on the other hand, employed for entities and phenomena of unknown and/or collective identity and property. The following are two typical excerpts (Chem 1012, 126; and 146) that respectively represent these categories.

> *Finally with regard to balanced equations, recall that convention dictates use of the smallest whole-number coefficients. Although the equation for the reaction between **molecular nitrogen** and **molecular hydrogen** to produce ammonia is, indeed, balanced, $3N_2 + 9H_2 \longrightarrow 6NH_3$; the coefficients are not the smallest possible integers representing the relative numbers of reactant and product molecules. Dividing each coefficient by the greatest common factor, 3, gives the preferred equation:*
>
> $N_2 + 3H_2 \longrightarrow 2NH_3$

The rhetorical *style* of the above quote directly addresses the desired position of molecules in making up the world and its substances. It explicitly mentions the status and form in which the two reactants are found, as *molecular nitrogen* and *molecular hydrogen.* Besides, the rhetoric is so accurate in portraying the true observations and evidence of the reaction.

> *The coefficients in the balanced equation are used to derive stoichiometric factors that permit computation of the desired quantity. To illustrate this idea, consider the production of ammonia by reaction of **hydrogen** and **nitrogen**:*
>
> $N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$

This one, as well, is an equivalently accurate figuration in that it is free from the *atom-ion-molecule* controversial interpretations and the overemphasis of the atom sorted under *functional* atomism. The corresponding state of the reacting entities, however, was not addressed directly as in the first quote. It just says *hydrogen* and *oxygen*. Beyond this, whether hydrogen and oxygen exist in the form of and are *atoms, ions,* or *molecules* is not addressed. That is why such rhetoric is referred to as "generic." There are also cases of these components where only chemical symbols and formulas are used without any additional reference to the same issue of addressing whether the reacting entities are *atoms, ions,* or *molecules*. In the following excerpt, for example, only *chemical symbols* were used to refer to the reacting metallic and molecular solids.

> *How many moles of **I_2** are required to react with 0.429 mol of **Al** according to the following equation?*
>
> $2Al + 3I_2 \longrightarrow 2AlI_3$

[Chem 1012, 147]

Segments associated with *argumentation* are, however, few in number or frequency. Much of the argumentation examined in the documents was found to imply the *functional* and *mechanical* notion of the atom. The majority of these cases were found good for context- and evidence-based expressions, explanations, claims, syntheses, and arguments with sounding, persuasive, and precise interpretations and inferences.

Although many elements consist of discrete, individual atoms, some exist as molecules made up of two or more atoms of the element chemically bonded together. For example, most samples of the elements hydrogen, oxygen, and nitrogen are composed of molecules that contain two ***atoms*** *each (called diatomic* ***molecules****) and thus have the molecular formulas* H_2, O_2, *and* N_2.

[Chem 1012, 57]

This argumentative quote acknowledges molecules as *chemically fundamental* and *independently-existing* chemical constituents of sample elements such as sulfur powder, hydrogen, and oxygen gases. This characteristic makes argumentation of this sort evidence- and context-based. Argumentations of this category are therefore characterized by well-addressed associations among all the corresponding symbols and methods of figuration for species and phenomena of known identity, properties, and context. Besides, these arguments were found interesting for linking constituents of stoichiometric calculations with the fundamentality and desired ontological stance of *atoms, ions,* and *molecules*—stoichiometric ontology and chemical atomism. Here is another quote that typically portrays how argumentation of such a form sounds. It explicitly addresses the *fundamentality* and *discreteness* of ions as chemical constituents of substances containing ionic compounds.

Ionic compounds are composed of discrete cations and anions combined in ratios to yield electrically neutral bulk matter. Keep in mind, however, that the formula for an ionic compound does not represent the composition of a discrete molecule, so it may not correctly be referred to as the "molecular mass."

[Chem 1012, 90]

The Mechanical Ontology. After all those years of scientific advancement and discoveries, the outdated ontological view of the 4th-century atomism was also found to still be implied by the rhetoric of the examined documents. As already addressed under the background section, the view claims the atom as an objectively existing entity and the building block of everything. Thus, atoms in this sense are corpuscular fundamental particles from which matter is formed (Bensaude-Vincent & Simon, 2008; Jensen, 2010).

More of the problematic segments of the data for this ontological theme belongs to the *linguistic* component of the analytical model. Both sub-types of these components—choice of words and syntax—were found in these segments. For the first sub-type, the choice of words such as *size, diameter, volume,* and *small* is the most problematic *in terms* of potential ontological implications. Such constructs are normally used for objects at a macroscopic level. The use of such words for atoms would therefore apparently prescribe the very *mechanical* notion. Here is one typical example of such a problematic *style*.

Whereas electrons occupy almost all of an ***atom's volume****. The* ***diameter*** *of an* ***atom*** *is on the order of* 10^{-10} *m.*

[Chem 1012, 47]

Volume is for something macroscopic and visible that occupies a space. The expression by itself wouldn't be as problematic and, of course, is based on values obtained experimentally. But it can be potentially shown to and interpreted mechanically by students during reading and classroom instruction, unless otherwise necessary, remarks are made by educators and teachers. Only a few others were discovered to be associated with both the syntax and choice of words. The following quote from the General Chemistry module (Chem 1012, 59), for example, is a distinctive indicator of such *syntax* and *choice* of words of interesting characteristics. The last sentence (the one in bold) sounds as if atoms have color.

> *A crystal of titanium dioxide, TiO_2, **contains** titanium and oxygen in a ratio of 1 to 2. **The titanium atoms are gray and the oxygen atoms are red**.*

The Reasons behind the Ontological Deviation. Vis-à-vis identifying those major themes of ontological views implied in documents, it has been the goal to understand and map the pattern in the overall rhetoric of the atom to uncover potential constructs to which the diagnosed ontological deviation is attributed. Accordingly, the four rhetorical components of the analytical model were used as pillars on which the pattern that appeared bolder was examined. As a result, the pattern of the overall rhetoric of the documents has been mapped and discussed in terms of five themes, of which only one corresponds to the desired precision. This entire process has been employed to identify those source domains from both the pattern and underlying associations between the themes of implied ontologies and those of the overall rhetorical pattern. The resulting findings are discussed as follows: *major themes* and *underlying associations*.

Major Rhetoric Themes

Theme I: No Noticeable Stance (Paradigm)

In the documents, there is no place or part where the preferred paradigm is explicitly addressed regarding the reality of issues like the atom and its ontology. As a result, it seems that the essence existence of species such as the atom, ion, and molecule is not as such indorsed. It would have been better if the documents in general had explicitly addressed stance synthesized from a well-established historical, philosophical, and scientific links with respect to context and evidences.

Theme II: Little Concern about Choice of Words (Style)

The other theme of the overall rhetoric pattern of the documents is associated with the linguistic perspective. As frequently addressed in the previous section, this linguistic perspective has two sub-components: the *syntax of sentences* and *choice of words, of* which the latter was found to be the most problematic in the examined documents. *"Contain (s)", "containing", "consist (s)"* and "*consisting"* are the words that were frequently used in a *rhetorically problematic* style. These words were used not just in a way that reflected the conceptual account of *chemical atomism* but also the principal account of *physical* and *chemical change*. Some others do have *sentences* of *ontologically problematic* syntax. Here is one typical example of the problematic *choice of such words* and *syntax*.

> *A crystal of titanium dioxide, TiO_2, **contains** titanium and oxygen in a ratio of 1 to 2. The titanium **atoms** are gray and the oxygen **atoms** are red.*

[Chem 1012, 59]

The underlined words in the first sentences of this excerpt are so generic that it is not distinguishable whether they are referring to an *atom, an ion, an element,* or a *molecule.* But, the elaboration in the second sentence implies that the authors, using those words, were referring to *atoms.* The word "*contains"* was also used in some sort of *mereological* or *mechanical* sense, as if the *titanium* and *oxygen* independently exited in TiO_2 bearing their very original atomic characters. Moreover, someone with an understanding of *the basics of Chemistry* can easily note that the syntax of the second sentence is even more problematic. The excerpt in general was a caption of a diagrammatic illustration of a solid crystal of TiO_2 solid using *gray* and *red* spheres to denote *titanium* and *oxygen* (Figure 2.7, page 59). The last sentence, however, sounds as if *titanium atoms* are *gray* and *oxygen atoms* are *red* in nature. This is so misleading since constructs such as *color* and *odor* can't be defined at such a microscopic level for individual *atoms, ions,* and *molecules*. There are also a few more forms of this type in which other words such as *size, volume,* and *diameter* are used in the same *rhetorically problematic* style.

Theme III: More Accurate Figurations of Observable Events

This is the most interesting theme that manifests the most desired perspective of atomism and its ontological basis: *chemical* atomism and *operational* ontology. This analysis revealed that the narration of those scientific facts and observations is not, as such, problematic. It was found to meet much of the expected accuracy. Because the descriptions and explanations of that scientific *evidence, facts, observations,* and *phenomena* are more *valid* and *accurate* throughout the rhetorical flow of the documents. The figures, in most cases, are s*traightforward*. When it comes to figurations of such *evidence, facts, observations,* and *phenomena*, the rhetoric appears precise. Many excerpts could be quoted as evidence of which the following is typical.

> *Although many elements consist of **discrete**, **individual atoms**, some exist as molecules made up of **two or more atoms** of the element chemically bonded together. For example, most samples of the elements **hydrogen**, **oxygen**, and **nitrogen** are composed of **molecules** that contain two **atoms** each (called diatomic **molecules**) and thus have the molecular formulas* H_2, O_2, *and* N_2.
>
> [Chem 1012, 57]

It was clearly stated in this excerpt that elements such as ***hydrogen**, **oxygen**, and **nitrogen*** are not found as ***discrete individual atoms*** in nature or under any other normal circumstances. This means that these species are *fundamentally* and *discretely* found as chemical constituents in the form of diatomic *molecules* only. The figuration of this form, therefore, acknowledges *not only atoms but also molecules* as *chemically-indivisible, independently-existing fundamental constituents* of substances in the world. This is exactly the kind of ontological view targeted by chemical atomism.

Similar forms of accurate and valid figuration have been found in other topics that discuss ions too. Here is one distinctive example from the same page that, in turn, guarantees equivalent ontological status for *atoms* and *ions*. It recognizes the [monoatomic] array of ions as chemically-indivisible and independently-existing chemical constituents of substances of ionic compounds. Many more such segments were identified from all the examined documents (Chem 201, 18; 19; 68; 70; 91; 92; 112; 114; 116; 117; 119; 136; 137; 138; 141; 143; 145 – 150; Chem 211, 20; 21; 23; 137; 138; 139; 154; 155; 157; Chem 1012, 16; 121; 146; 147; 151; 155; 161; 171; 172).

> *Ionic compounds are composed of **discrete cations** and **anions** combined in ratios to yield electrically neutral bulk matter.*
>
> [Chem 1012, 90]

Theme IV: Inconclusive Argumentation

Next to the *choice of words,* this is the second rhetorical component that appeared poorly maintained. The rhetorical pattern of this form, in general, is made up of four sub-types, which are respectively associated with failing to rely on *experimental data* and *observations,* missing the very *chemical* perspective, lacking a clear ontological foundation or basis, and sounding historical, philosophical, and scientific links to context and evidence. In all cases, there is a gap between linking constituents of stoichiometric calculations with the fundamentality and desired ontological stance of atoms, ions, and molecules—a gap of *functional* atomism in which only the atom is *solely emphasized*. The rhetoric pattern was also found to lack the most operational experimental thesis and evidence of chemists and philosophers in the chemistry of the 19th and 20th centuries, such as Wilhelm Ostwald, Claude-Louis Berthollet, Antoine-Laurent Lavoisier, and John Dalton, especially in the way that it entertains counter-arguments from reductionists, physicists, and philosophers of physics (Bensaude-Vincent & Simon, 2008; Rocke, 1984).

Underlying Associations. As a result of the abductive analysis mentioned in the previous sub-section, it was found that most of the sorted initial codes in those themes of the overall rhetorical pattern of the documents are associated with certain types of implied ontologies. Every single possible categorical case of the implied ontologies and rhetoric patterns has been taken and checked throughout. The resulting association is illustrated as follows in Figure 2.

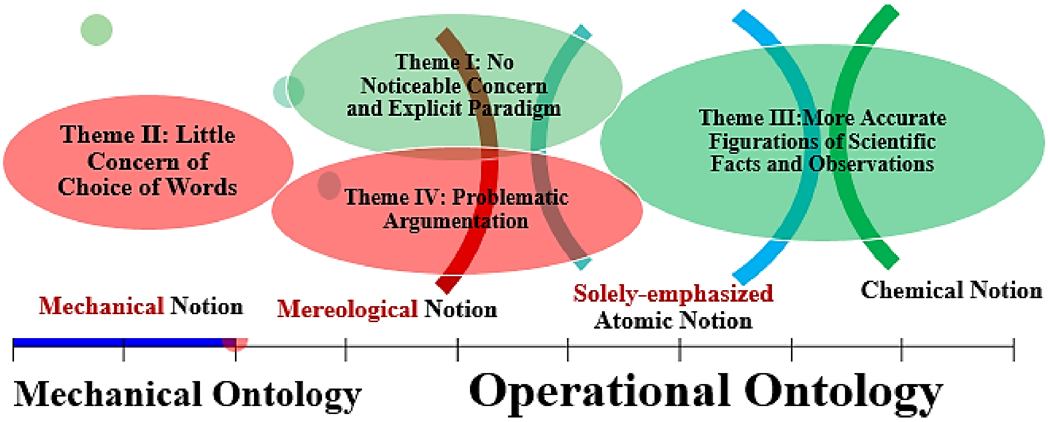

Figure 2: Underlying associations between the themes and endorsed ontological views

As can be understood from this figure, almost all cases of Theme III are associated, in one or another way, with the more desired atomistic view and implied ontology: *chemical* atomism and *operational* ontology. In particular, it is associated with the most desired atomic notion of this ontological category, the *chemical* notion of the atom. Themes I and IV were discovered to be more closely related to *mechanical* ontology and the *mereological* atomic notion. In this regard, the categories of *argumentations* and initial codes sorted under it (Theme IV) were found to be more related to *operational* atomism, while the lack of explicitly addressed paradigm or ontological stance (Theme I), regarding the essence of the atom as a scientific reality, was found to be equivalently attributed to the attainment of *operational* and *mechanical* ontological positions. Poor concern for word choice, on the other hand, was found to be associated with both the *mereological* and *mechanical* notion of the atom. This implies that the words that experienced chemists and instructors, such as the authors and validators of such documents, unintentional use can potentially lead to the attainment (by novices and students) of the outdated notion of the atom. For example, the following excerpt was taken from the second chapter of Chem 1012 module, page 57 to 79.

> *"Understanding the relationship between the masses of atoms and the chemical formulas of compounds allows us to quantitatively describe the composition of substances" [P. 57]; …*
>
> *"This identifies the elements titanium (Ti) and oxygen (O) as the constituents of titanium dioxide, and indicates the presence of twice as many atoms of the element oxygen as atoms of the element. A titanium crystal of titanium dioxide, TiO_2, <u>contains</u> titanium and oxygen atoms in a ratio of 1 to 2" [P. 59].*

The first part (from page 57) is so *stoichiometric* or *operational* in its ontological sense as it explains the constituents in terms of *quantifiable* atoms. So, it was taken as segment of the data or initial code, and sorted under the theme of the *operational* ontology of the first category or research question. The next sentence is an explanation about the former ontological claim. But, the composition is explained in terms of the *atom* only. This means that the status of array of ions as fundamental constituents of the crystal was not taken into consideration. Thus, the *functional* atomism, in which everything is explained in terms of the atom or the atom is solely emphasized, is portrayed within such an *operational* ontological synthesis. This is basically a problem of explanation and justification, which both are categorized under *argumentation*. Hence, problematic argumentations were found to lead to the manifestation of the *functional* notion of the atom (theme IV).

Choice and use of "contain" in the third sentence, on the other hand, gives a mechanical sense. This is also problematic in that it sounds the nature of the crystal is the totality of individual properties of titanium and oxygen atoms. As a result, this one was found to portray the *mereological* notion of the atom. Poor concern of word choice was, therefore, found to lead to the manifestation of the *mereological* notion (theme II) together with the previous case of problematic *argumentation* (theme IV).

DISCUSSION

Regarding the Implied Ontological Views. There has not been much literature regarding how the atom is ontologically portrayed in one's curriculum. It was, however, indicated in those few studies that such ontological aspects of the atom as the nature and essence of its knowledge have never been explicitly addressed in the examined curricular materials (Perez *et al.,* 2017; Taber, 2003). Justi and Gilbert (2000), for example, noticed in their textbook analysis that a finite number of models of the atom, with numerous ontological implications, exist within the school curricula of chemistry. Taber (2003) also concluded from his meta-analysis that much of the UK's curriculum lacks an explicit philosophical basis regarding atomic ontology. He also added that the National Chemistry Curriculum, at different grade and age levels, portrays different atomic notions with contradictory ontological implications. According to Taber, the very definitions of "atom" in different textbooks reflect different atomic ontologies. Here is an excerpt from his remarks.

> *Definitions from text books also often reflect an atomic ontology. Some text book definitions of the atom available to learners are vague (the "smallest possible amount of an element" (OSP, 1993)); virtually meaningless ("the smallest particles that can be obtained by chemical means" (Morris, 1991, p. 264)); or simply wrong ("the smallest particle of an element that still shows the chemical properties of the element" (Taber, 2003, 64).*

Perez *et al.* (2016) have also reported that the reality of the atom, its operational conformity, and relevancy were only *implicitly* in two of the six globally known and used textbooks of General Chemistry that they analyzed. They, in general, concluded that the status is not satisfactory in the case of the two textbooks and missing in the remaining four textbooks.

The findings of this study, therefore, agree with much of the literature on both the curriculum's failing to explicitly address the issue of atomic ontology and its implicit prescribing of numerous notions of the atom with contradictory ontological implications. There are, however, both similarities and differences in the types of prescribed atomic notions and ontological views. The findings of *operational ontology,* as the major ontological stance implied by the curricular sense of the atom, do only agree with the findings of Perez et al. (2016). The findings of *mechanical ontology* as another implication of the curricular sense of the atom, on the other hand, coincide with those of Justi and Gilbert (2000), Niaz and Coştu (2009), and Taber (2003). Similarly, the notion of *excessive emphasis* on the atom as well as the *mechanical* notion were found to overlap with what was reported in Niaz and Coştu (2009) and Taber (2003). However, the mereological notion of the atom has not been found in the examined literature.

Regarding the Potential Reasons behind the Ontological Deviations and Contradictions. The findings in general show that the authors and validators of those documents were not so concerned with the type and possible implications of words they had been using throughout their modules. This resembles what scholars such as Newman (2016) and Taber (2003; 2000) have noticed from their experiences and meta-analysis. The developers, authors, and validators of the documents are experienced university instructors – assistant or associate professors and lecturers. Thus, they would have no trouble identifying the difference between an atom, an ion, and a molecule. But they still select and use problematic words that endorse outdated and undesired views – very confusing and differently interpretable jargons that they themselves are not confused by. This is like what Taber (2003) described as *chemists sometimes refer to everything being made of atoms and talk and write as if atoms are the conserved entities in chemical reactions... [such] shorthand talk of substituting atoms creates no complications for expert chemists*.

For the first component of the analytical model, *paradigm,* the problem of *lacking an explicit stance or preferred worldview* was also reported in Perez *et al.* (2016) and Taber (2003). The missing links with the HPS perspective of the reality of the atom, the nature of its knowledge, and its essence in science education were also found to agree with most of the examined literature, including Justi and Gilbert (2000), Niaz (2014), Niaz and Coştu (2009), Niaz and Maza (2011), Perez et al. (2016), and Rodriguez and Niaz (2004). It is like as Niaz and Coştu (2009, 239) concluded in their report, the p*resentation of atomic structure in Turkish general chemistry textbooks* is as follows.

> *This study shows that general chemistry textbooks published in Turkey (1964 - 2006) generally lack a history and philosophy of science perspective.*

SUMMARY AND IMPLICATIONS

Summary. This study aimed to examine and discuss how the atom is ontologically presented in the curricular documents of chemistry teacher education in accordance with the persistence of the outdated notion of the atom and its corresponding ontological deviation. Consequently, no explicit reference to the preferred paradigm and ontological basis of the atom was found in any of the documents. However, two ontological views were found to be implied by the entire rhetoric pattern of the documents—the targeted *operational* ontology with three different atomic notions and outdated *mechanical* ontology. The rhetoric, on one hand, is more accurate and valid in figurations of observable events, while, on the other hand, is very problematic in explaining, interpreting, and inferring data, evidence, and contexts from those philosophical and scientific inquiries into the reality of the atom and the nature of its knowledge.

The findings in general imply that the rhetoric of the existing curriculum of teacher education does partially portray the very outdated ontological schools of the atom and the underlying misconceptions that have been persistently found in the examined literature. These ontological deviations, as well as the persistence of the underlying atomic notions, are linked to a lack of an ontological stance, a lack of concern for word choice, and problematic argumentation. So, it can also be concluded that due consideration of the historical, philosophical, and scientific aspects is very essential to set a clear and explicit foundations. Besides, the *stylistic* aspect of the rhetoric needs to be taken seriously by the authors, reviewers, and validators, not in the way that emphasizes what they mean, but in the way that the words and their operational use really imply.

Besides, much effort should be expended to ensure that the explanations, elaborations, interpretations, claims, and inferences made in these documents are best aligned with historical, philosophical, and scientific evidence, observations, and contexts.

Implications for Addressing the Diagnosed Ontological Gap. The key issues that needed to be reconsidered in the examined documents are the essence of explicit ontological foundation regarding the reality of the atom, choice of words, and soundness of the arguments, especially in terms of all the perspectives of atomism, contexts, and evidence of the history and philosophy of science (HPS). The following suggestions are, therefore, formulated in accordance with addressing the diagnosed ontological and conceptual deviations.

First of all, further investigation into the respective documents, HPS, as well as that of the curriculum at the corresponding different levels, are highly recommended to have a better and more detailed understanding. These issues should be incorporated into the orientation, guidelines, revision, and validation of modules of these courses and other documents to be developed or revised in the future. The Federal Ministry of Education, City and Regional Education Bureaus should, in this regard, take the initiative to make these three problematic issues part of the material development and validation processes.

Second, the organization of inter-institutional and intra-institutional periodicals such as seminars is very essential in which findings from the curricular and historical analysis and HPS-cases are raised, evaluated, discussed, and authenticated to identify inputs for future interventions and reforms in the curriculum and initiatives such as Induction Workshop (IW), Higher Diploma Program (HDP), and Continuous Professional Development (CPD). The other suggestion that needs to be taken optimistically is to integrate the rhetoric issues into the initiatives of teacher education institutions. Universities and colleges of teacher education should take the initiative in planning, financing, and implementing such suggestions. Accordingly, curriculum revision can be requested based on the authenticated findings, evidence, and experience to be obtained from the implementation of the aforementioned initiatives of the first two suggestions.

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