HOW WORTHY IS DALTON'S PURSUIT OF CHEMICAL ATOMISM FOR THE PROSPECTIVE TEACHERS? A CASE OF KOTEBE UNIVERSITY OF EDUCATION, ETHIOPIA

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Abstract. *Atom possesses controversial ontological accounts even in a single discipline such as chemistry. Its essence as a reality and inclusion in science education has been subjected to numerous philosophical and scientific debates. The educational literature also shows that the ancient corpuscular notion is dominantly portrayed within the curriculum and instruction of many educational settings. The fundamental problem is that the chemists, educators, philosophers, and historians of chemistry themselves haven't had a substantial agreement on any of the philosophical and scientific accounts due to their longstanding philosophical divide between the different positions of positivism and realism. Neither has the historical perspective of philosophy and science been reasonably acknowledged in science/chemistry education. We aimed in this interpretative case study to figure out how much Dalton's pursuit of the chemical atomism is worth to 22 purposely selected and interviewed prospective teachers. The resulting transcripts were analyzed using HPS, the seven milestones of its case study. As a result, one major and two minor themes were found none of which match any of the themes of the milestones. Moreover, the entire narrative lacks some essential perspectives and contexts of HPS in general and Dalton's experimentations in particular. Misjudgment of his indivisibility notion, for example, is a drawback associated with this limitation. Thus, more inquiries are needed to be conducted in the long run into the curriculum and classroom practice while departmental discussions on such issues are suggested in the short run.*

Keywords: *Atom; Atomism; Atomic Theory; Chemical Atomism; History and Philosophy of Science*

INTRODUCTION

HISTORICAL AND PHILOSOPHICAL OVERVIEW

The wonder of what the world is made of starts with the life of mankind. A historical trace of this inquiry, however, takes us to the 1200s before the birth of Jesus Christ [1]. Literature of the Chinese Alchemy is the first in which this issue was raised. It then appeared in the Indian 9th BC Jainism, 6th/5th (BC) Hinduism, and Buddhism. The first defined version of atomism, however, emerged in Greece around 4BC as 'Corpuscularism'. It actually has two opposing schools of thought: Democritian Atomism and Aristotelian Anti-atomism [1]. Democritian atomism states that the divisibility of matter has a

certain limit on which these indivisible corpuscular minima, which are no more divisible, are obtained [2] [3] [1]. The Aristotelian view, on the other hand, rejects the idea of 'atoms' as corpuscular primary substances though it acknowledges the existence of corpuscles in the form of natural minima. Ontologically, this school of thought rejects the existence of atoms as any sort of reality. That is why it has been known as Aristotelian anti-atomism [4] [5] [1]. The debate between the two views continued to the 5th (AC) century at which corpuscularism started to enter a state of burial due to religious suppressions [2].

The time from the 5th AD up to the 15th AC (476AD – 1492AC) corresponds to the era of Medieval Philosophy accompanied by Islamic and Christian atomism. This was the era when the ontology of the atom became the core of potential philosophical and religious debates. The debates were also driven by the religious concern of eternality and creation. It was extended to the issue of whether atoms exist as reality or not in the 12th century, and continued until the 14th century. As their sole emphasis was maintaining the divinity of God, both Christian theologians and Islamic atomists denied the existence of real causality, including atoms, in the created world [6].

A prominent development was observed within the 16th to 18th-century Philosophy in which the very first versions of corpuscularism were revived. It is a period when classical corpuscularism was revived by mechanical philosophers. Similarly, the Aristotelian Anti-atomism was also brought back to the debates from which physical and chemical atomism emerged as separate disciplines [2]. The mechanical notion of physical atomism issues ontological autonomy for atoms while the discoveries of Priestly and Cavendish guarantee an autonomous position for molecules such as those discovered by them [5] [3] [1].

This is followed by the 19th Century's very first scientific notions of atomism [2] [3] [1]. Syntheses of Lavoisier, Dalton, and the discoveries of Jacob Berzelius's (1779 – 1848) in electrochemistry, chemical bonding, and stoichiometry created a brand-new operational perspective of chemistry that promotes the scientific notion of atomism [5]. It, however, has been subjected to potential critics and unavoidable claims from advocates of the emerging schools of Realism: Naïve realism, conjectural realism, and scientific realism - conjectural realism at one and Scientific Realism at another pole [4] [5]. Kinetic atomism, stoichiometric atomism, agnostic atomism, and anti-atomism are the schools of atomism that emerged in the 19th century. Consequently, the existence of the atom as a fundamental reality became most controversial. In the 20th century, disproval of some of Bohr's assumptions made the reality of the atom uncertain while the quantum projection of atomic orbitals was started to be used as an indication for atomic ontology [4] [5] [2]. John Dalton is entitled in HPS as a founder of chemical atomism and its philosophical basis, operational realism [7] [8].

MAJOR MILESTONES IN DALTON'S CASE STUDY OF HPS

John Dalton was first interested in natural philosophy and meteorology. In Kendal, where he was serving as a teacher in a Quaker school, he acquired the habit of keeping records of meteorological phenomena [6]. Historians of science believe that this interest in meteorology eventually led him to a series of related questions. The issue of 'why the gases did not separate in layers according to their densities' is the core of these questions. Dalton was wondering this when he formulated his first idea of experimentation. Thus, the scientific wonder of Dalton was started as the first theory of mixed gases and made its way to the quantification of the atom in which the very operational philosophy of chemistry has been realized [7] [8]. This is one aspect of HPS that constituted the seven major stages as milestones in Dalton's pursuit of the development of the quantitative atomic theory.

The first remarkable achievement in Dalton's quest is the law of partial pressure in the samples of mixtures of different gases. Thus, this law is the first (1st) milestone from which he proposed his first theory of mixed gases that he proposed in 1801. In his continued observations

of this theory and underlying hypothesis of "equal volumes-equal numbers" (EVEN), he noted, against his former reciprocal assumption, that oxygen gas is denser than water vapor. As a result, he realized that his simplest approach to determining atomic and molecular weights, and vapor densities, doesn't work as hoped. This forced him to turn his attention to alternative perspectives. Accordingly, he devised a new theory of mixed gases in 1805. This one is called the "second theory of mixed gases", the second (2^{nd}) milestone [8]. As he continued to plan and experiment with his second theory, he appeared to face another conflict. This one is more associated with the phenomena of dissolving different samples of gases in water that he presupposed as purely physical. This made Dalton wonder about the possibility of chemical interaction between gases and water. Consequently, Dalton discovered such a chemical force of interaction in solutions of gases and water, the third (3) milestone [9].

He was also able to notice multiple proportions of constituent atoms in the underlying analyses and determine molecular weights of different substances such as ethylene and methane. The resulting "law of multiple proportions" and the "first table of atomic weights" are respectively the fourth (4^{th}) and fifth (5^{th}) milestones of his pursuit in the case study of HPS. These analyses were carried out using "the rule of greatest simplicity". As a result, he was studying the power of affinity from which he developed the "power of affinity" model, the sixth (6^{th}) milestone.

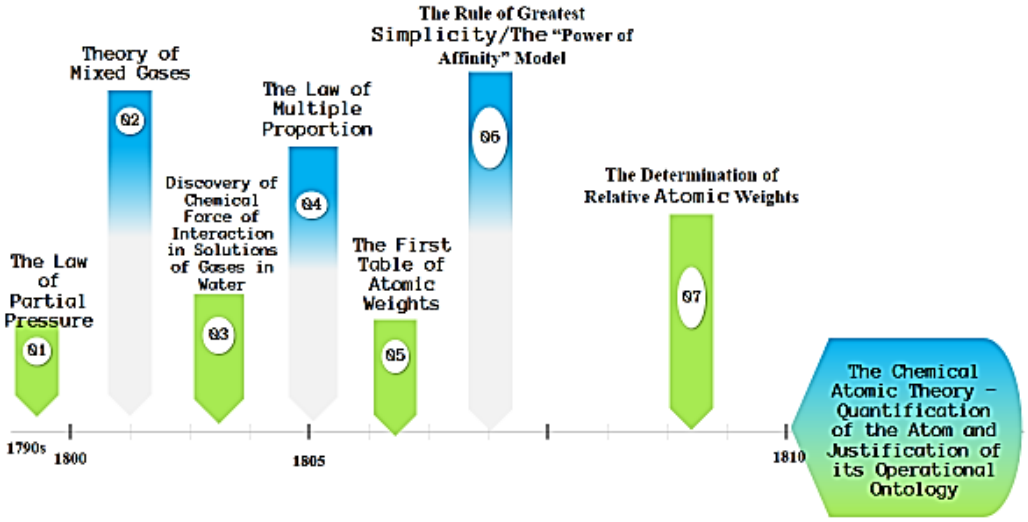

Figure 1: Major Themes of Milestones of Dalton's Timeline in HPS

In general, the possibility of the chemical force of interaction that Dalton noticed brought an important shift in his perspective of thinking. That is what enabled him to make his way toward the law of multiple proportions and develop the first table of atomic weights and the power of affinity model. All the latter discoveries were achieved, published, and debated between 1805 and 1808. In addition, Dalton extended his table of atomic weights in which he was able to quantify different atoms in terms of atomic weights. Hence, the determination of relative atomic weights is another milestone, which can probably be labeled as the seventh (7^{th}) milestone.

Thus, such a turning point in Dalton's thinking enabled him to quantify the atom and its role in the formation and existence of those familiar kinds of stuff. As a result, Dalton came up with a New System of Chemical Philosophy. The first version of this book was published in 1808 and while the second one was in 1810 [8]. The chemical theory of the atom was the core of

this philosophy in which the existence of the atom was both philosophically and scientifically justified [7] [9]. That is also the new way of thinking and investigative practice that historians and philosophers, such as Emile Meyerson and Ernst Cassirer, recognized as the foundation and realization of operational realism as the chemists' way of dealing with and observing reality in action [8].

ADDITIONAL VALUES ATTACHED TO DALTON'S PURSUIT OF CHEMICAL ATOMISM

Beyond the accomplishment in these milestones, Dalton is well acknowledged for being so critical – considering all the perspectives of his contemporaries and previous scientists and philosophers, being respectful to perspectives and arguments that have been distantly declined by even scholars of his type, critical analysis and use of previous experiments and evidence. The physical and chemical atomic theories, elemental equivalents, and the formula problem are the core issues of such scientific and philosophical negotiations [7] [8]. Despite being a founder of the chemical atomic theory, Dalton, for example, was able to realize that the physical atomic theory works within its physical and mechanical realm. In fact, the very first version of the physical atomic theory states that matter consists of hard, unsplittable, impenetrable, spherical atoms surrounded by a caloric fluid, exerting forces on their neighbors and cohering into definite arrangements. Whereas the chemical atomic theory states that there exists for each element a unique "atomic weight", a chemically indivisible unit that enters into combination with similar units of other elements in small integral multiples. Even though many scientists have been criticized for attacking the physical theory, Dalton was known for defending both theories within the boundary of their points of view and applications (1984). His notion of the chemical atom was accepted by scientists such as Robert Boyle who even took only physical minima naturalia as primary corpuscles. For Boyle, chemical atoms are concretions of primary corpuscles that remain as the final products of chemical analysis [7]. Such postulates are, however, rejected by Lavoisier who regarded them as mere metaphysical speculations [8]. For Lavoisier, such speculations contribute nothing to actual experimental work since atoms have no empirically determinable properties [7].

Regarding elemental equivalents as well, Dalton was well aware that his weights were based upon assumed formulas and thus had an uncertain foundation. He only considered his assumptions as very probable. Unlike Wollaston, Dalton was also able to be well aware of and consider the issue of molecular reality. Dalton in the first volume of his book paid due attention to Lavoisier's operational and analytical definition of "elementarity". He also referred by "elementarity" to simple bodies that have not been decomposed but are found to enter into combination with other bodies. Unlike Lavoisier, Dalton does wish to ascertain the compositional nature of such elementary substances. His key assumption is that chemical elements are composed of 'ultimate particles' or atoms and that the least part of a chemical compound is made up of combinations of atoms of the component element [7] [8].

According to [8] chemical atomism was wrongly manifested as stoichiometry by many 19^{th}-century chemists and 20^{th}-century historians. But, it can be noted from Dalton's works that stoichiometry is concerned with the law of equivalent proportions, which, in one of its forms, states that all chemical reactions take place in proportions elemental equivalent weights. But, chemical atomism is more theoretical in nature though it has been criticized for lacking an explicit model as either a visualizable or explanatory vehicle. What has been obeyed in either way is that atoms are the chemically-indivisible fundamental units with fixed elemental weights and the ability to combine with variable proportions. This is the notion that has been used to explain the chemical formation and composition of all known compounds. This is the chemical atomism that Dalton came up with [8].

THE GAP AND RATIONALE OF THE STUDY

Historians and philosophers of science, such as [8] [5] and [7], have been stressing the impact of the long-standing neglect of the very chemical aspect of chemistry in general and atomism in particular on the quality of its development and education. Alan J. Rocke, for example, strongly claimed that the very revolutionary, philosophical, and scientific notion of Dalton's chemical atomism has not been fairly acknowledged and worked on in the 20th century [8]. Accordingly, several studies reported that the corpuscular notion is still being solely portrayed within the educational settings despite all the scientific discoveries and advancements. It includes countries such as UK [10] [11] [12], USA [13] [14] [15], Turkey [16] [17], and Ethiopia [18]. The curriculum in general has been criticized for failing to address the being and essence of the atoms and overemphasizing the electronic aspects discovered in the 20th century [14] [15].

A cross-age study conducted on Turkish students' mental models of the atom reported that much of their narrative manifests the Democritus notion of mechanical ontology [16]. Similarly, a content analysis of general chemistry textbooks published in Turkey (1964-2006) conducted by [19] revealed that the books generally lack essential historical and philosophical perspectives. Another paper on 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 (analogies, metaphors, models, and other 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 [12]. [13] 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. Hence, it has been criticized that much of the curricular and instructional sense of the atom lacks essential cases and contexts of HPS in general and Dalton's perspective of chemical atomism in particular.

Accordingly, [9] have reported that most of the statements of 28 undergraduate students lack essential contributions of Dalton's work to the development of the modern atomic theory. [9] reasserted, in this regard, both the aforementioned poor and distorted manifestation of HPS as well as the appeal for a re-examination of one's chemistry education in which an improved conception of the nature of chemistry would be optimized from a study of its history. As a result, they developed a synthesis of the account of Dalton's work as a case study of HPS. However, the issue of the extent to which this account is manifested in one's curriculum or thinking remained unknown in many educational settings including ours.

This study, therefore, aimed at finding out how worthy Dalton's works are to those prospective teachers and discuss key implications for addressing those aforementioned persistent misconceptions and learning difficulties. The key research questions that, therefore, needed to be addressed are:

(a) How well is Dalton's development of the new philosophy of chemistry and chemical atomism acknowledged within the prospective teachers' narratives of the atom and its theories?
(b) What implications does the diagnosed level of awareness have on the persistent misconceptions and learning difficulties?

METHODOLOGY

The study is concerned with the prospective teachers' thinking of the historical development of atomic theory that they attained from their secondary and teacher education. Within such thinking, the worth of Dalton's contribution to quantifying the atom is of higher concern. This concern was taken as an important

case of interest. Hence, the case study design was preferred. It involved analysis and description of all possible interpretations of the participants' thinking. For this reason, the Merriam qualitative approach of the case study was employed so as to meet this purpose.

The participants were purposefully selected second and third-year pre-service teachers of Kotebe University of Education (KUE). It is the second-oldest public university in Ethiopia. It began in 1959 as the Kotebe College of Teacher Education of Haile Selassie I University. In 2014, it became Kotebe University College. In 2016, it was re-established as a Metropolitan University in the capital of the country with the primary aim of addressing the human resources of the city. Currently, it is being re-established as Kotebe University of Education. So, it is the only educational university in the country. That is why it was purposely selected. Besides, it is the only university in the country that is currently offering all modalities (pre-primary, environmental science and mathematics, integrated science and chemistry) and levels (pre-primary, lower primary, upper primary, secondary, and preparatory teacher education).

Level-wise, the participants are of two types: pre-service diploma teachers of the integrated science stream and first-degree undergraduate chemistry students who, according to the current consecutive modality of teacher education for secondary schools, have the opportunity of applying for being recruited as teachers and attending the one-year postgraduate diploma training (PGDT). They are 18 (13 second-year and 3 third-year) in number while those pre-service teachers are 49, who all are third-year.

In the process of this purposive sampling, specific techniques of average/normal, unique/exceptional, and, lower/higher characteristics were employed. To do so, a preliminary survey was administered to all the pre-service teachers and undergraduate students. The survey asks them for permission to access their official profiles from the registrar as well as request information on their gender, age, willingness to take part, attitude towards the selected chemistry course, cumulative academic achievement, and interest in joining their field of study, and being a teacher. The resulting evidence was organized and compared against the one from the registrar and department offices. Selecting every desired participant, interviewing and coding have been carried out based on this information until the saturation was attained on the twenty-second one.

Accordingly, an interview protocol was prepared based on those findings from the literature on the diagnosis of alternative conceptions of the atom, HPS, HPS-based case studies, and interventions. The items are concerned with issues such as what and how things are made of; mental models of atoms; teaching-learning experiences; grade level they were introduced to the issue of atoms; the context in which they constructed such mental models; their belief in the relevancy of the contents; and the nature of the selected substances at the microscopic and macroscopic levels. Thus, it was employed as a major instrument of data collection. The resulting data was analyzed through categorical coding in which constant comparison was employed as per the suggestion of Merriam [21] [22]. The analysis used HPS in general, and the theoretical synthesis of [20] case study on the development of Dalton's atomic theory in particular as analytical frameworks. Thus, the milestones of the case study were used as major themes against which the initial codes were identified, examined, and sorted in the process of coding.

RESULTS

THE WORTH OF DALTON'S PURSUIT AS ONE CASE OF HPS

One major theme was found in this analysis. It is something associated with the first atomic theory, which we labeled as "proposed the first atomic theory". Hence, it doesn't match with any of those milestones of Dalton's works formulated from HPS. Because "proposing an atomic theory" is not one of Dalton's milestones according to the HPS case study. It is rather the ultimatum of Dalton's quest. The underlying sub-themes are also more associated with such

construct than the targeted milestones. In addition, two more minor themes were established from the participants' narrative of the atom and its theories. Again, both were found to not much any of the themes from the HPS case study. The key findings are, in general, summarized as follows in table 1.

Table 1: Summary of the resulting themes

Themes	Sub-themes	Number of segments	Proportion of sub-themes	Proportion of the themes
Introduced and Advocated Experimentation	Using previous laws and evidence	2	3.00%	10.60%
	Planning and conducting experiments	5	7.60%	
Proposed the first Atomic Theory	Disproving Aristotle's notion of continuity	5	7.60%	
	Introducing an atomic theory; of five postulates	41	62.10%	80.30%
	Proving Democritus' notion of discontinuity	5	7.60%	
	Mistaking the divisibility concept	2	3.00%	
Introduced the First Atomic Model	The ball model	4	6.10%	
	Lacking knowledge of and incorporating an explanation of the inside part of the atom	2	3.00%	9.10%

The First Atomic Theory

As can also be noted from Table 1, this is the theme of the category of the first research question that appeared so intense. It constituted four sub-themes: "disproving Aristotle's notion of continuity", "the five postulates", "proving Democritus' notion of discontinuity", and "mistaking the divisibility concept". The majority of the segments of the data fall into this theme. Because proposition or introduction of the first atomic theory has been acknowledged in much of the narratives of Dalton's works and milestones. The "five postulates" are the core of these narratives while "proving Democritus' notion of discontinuity" and "disproving Aristotle's notion of continuity" were shortly implied. Most importantly, the shift in the focus from the theorization of matter to that of the atom was traced, within a few narratives, as an important turning point of HPS. ***Beakal Abate*** (name changed) is an undergraduate student who belongs to the "Excellent" and "Moderate" categories of academic achievement and attitude towards the selected courses, respectively. He is among the few participants, quoted below.

> *Then, Dalton came, John Dalton. There was evidence; he conducted some experiments*

> *using the law of combination found by Antonio Lavoisier. Dalton used these laws and conducted experiments. Accordingly, he moved the theory of matter to the theory of the atom.*

Almost all of the remaining segments are concerned, in one or another way, with the "correct" and "wrong" postulates of the atomic theory. These portions of the participants' senses were found to be the direct reflection of the curricular values attached to Dalton's and the modern atomic theories. Because those postulates associated with "divisibility", "similarities in properties of atoms of the same elements" and "possibility of transformation of atoms of a given element into another elements" are the core issues emphasized in these segments. For the majority of the participants, the historical narrative of the atom and its theories appeared to be nothing more than a simple comparison of Dalton's and the modern atomic theory. ***Senay Demeke*** (name changed) is among the few female undergraduate degree students with *satisfactory* academic achievement (2.00 – 2.49) and a *low* attitude towards the selected courses. She briefly put the whole historical development as such a starting-and-closing concern of Dalton's and the modern atomic theory.

> *There is also modern atomic theory after Dalton. I also teach that. The modern atomic theory was proposed by accepting some of the Dalton's and improving the remaining.*

In fact, this notion was found to be differently implied by much of the other participants' senses too. There are even segments that appeared so replicate to the previous quote from **Senay**. The following excerpt from another pre-service teacher renamed ***Nebil Wasihun***, is among these segments of the data.

> *The modern atomic theory was proposed by accepting some of the Dalton's and improving the remaining.*

Tigistu Beza (name changed) is a graduating prospective teacher of **Integrated Science** (grade 5 and 6) with an *excellent* cumulative (CGPA of above 3.50) and a *moderate* attitude towards the selected course. He echoed in his narrative those remarks in the module of the general chemistry (Chem 211) (DoC, 2015), which he took in his second year.

> *As you know, three of the postulates of Dalton's atomic theory were found to be wrong according to the modern atomic theory. First of all, Dalton said the atom is indivisible; but, it is divisible according to the modern atomic theory. Second, Dalton stated that atoms of the same elements are the same. Again this is wrong since isotopes are different in physical properties. The other one is … is that Dalton stated atom of one element can't be changed into the atom of another atom. This is also wrong according to the modern atomic theory.*

An attempt in obtaining ***Tigistu's*** own interpretation of these statements didn't succeed as he came up with list of similar statements of three of the six postulates. Other participants such as ***Gelanie,*** whom quoted below, preferred to emphasize only on one of the postulates. "Divisibility" and the historical Aristotle-Democritus debate of "discontinuity" were the core issues in this sub-theme of their judgment.

> *Dalton said the atom is indivisible. But, I believe in the divisibility concept. In modern atomic theory, what we are using is this divisibility concept. There are sub-atomic particles.*

In such segments, the overall accomplishment of Dalton's works is portrayed

in general in terms of two more sub-themes: proving Democritus' notion of "discontinuity" and disproving Aristotle's notion of "continuity" (Table 1). The following quote from ***Tigistu's*** elaboration is a typical example in which Dalton's success was interpreted in terms of resolving the historical Aristotle-Democritus debate.

> *Aristotle, it right you know, was following the continuity theory. Isn't it? He said if we keep breaking something, it is difficult to reach the end. That means divisibility has no limit. So, he was an advocate of the Continuous Theory of Matter. That is the theory remained accepted for a very long time. But, Dalton disproved it.*

Most importantly, it can be noted that such critiques of Dalton's postulate about atoms being indivisible don't take the contexts of his investigation into consideration. It could have been better if the shift in point of view that Dalton made in the transition from his first theory of Mixed Gases to the discovery of the possibility of chemical interaction between gases and water in solutions. Because anybody with due notice of such a shift can figure out that Dalton was talking about a chemical sort of divisibility in his atomic theory. An atom, from this perspective, is not chemically divisible. The discovery and existence of sub-atomic particles by themselves doesn't imply the chemical divisibility of the atom. Atoms can be disintegrated into sub-atomic particles in the form of rays only by nuclear approaches. Such divisibility is, however, not chemical. That is why some philosophers and historians of science, such as Rocke (1984), Viana, and Porto (2009), referred to his theory as "the chemical atomic theory".

The Ball Atomic Model

Introducing a ball model as a portrayal of his descriptions of the atom is another theme traced from the diagnosed senses. But, this appeared to be much lighter than the previous theme, which is why it is discussed as a minor theme. Because a little was able to be traced to it of which the following was quoted from ***Sultan Beshir***, a second-year undergraduate degree student with a respectively *good* (2.50 – 3.49) and *moderate* level of academic achievement and attitude towards the selected courses.

> *He theorized and proposed a model to the level of available evidence and his understanding allowed him. He imagined the atom as a ball; there is the quantum mechanical model; there is Dalton's model too. There is also the Thomson model.*

Again, such atomic portrayals are not free from those kinds of critiques of "correct" and "wrong" postulates discussed in the previous sub-section. Dalton's portrayal was criticized for lacking understanding and description of the inside of the atom. The following is an excerpt from ***Sultan's*** continued elaboration.

> *For example, John Dalton said the atom is this at the beginning. What he said is a solid indestructible sphere. Because he didn't know about the sub-atomic particles. Electrons, protons, and neutrons were not discovered at that time.*

This notion of the atom was even entitled to be outdated though the HPS-literature shows it as philosophically and scientifically founded on recent inquiries and evidence. ***Beakal***'s comment on the probing cases of persistent alternative conceptions and learning difficulties raised during the interview is typical among the few segments of such senses from ***Werkneh*** and ***Tsega***.

> *You know there are different models. Even at their high school, there are Dalton, Thomson, Rutherford, Thomson,*

> *and then Quantum Mechanical models. What you were telling me now is that their conception is that of the atomic notions that existed even before a Dalton. This means that they were stacked on the classical model.*

Relying on Experimentation

This is the other minor theme established from the analysis. In segments of this theme, the worthiness of Dalton was explained in terms of *noticeable inclination toward pre-planned experimental inquiries and resulting evidence.* Those claimed achievements of Dalton's works were also acknowledged as more genuine and precise. In fact, such acknowledgments were linked to those attributes of Dalton's theory and model discussed in the previous two sub-sections. ***Abebe Desta***, whom to be quoted next, and the previously quoted ***Beakal*** are the two participants with segments of this sort.

> *What has been discussed in those theories and models are made based on the experimental evidence. It is not just theoretical. The theoretical was there only before the era of John Dalton. Starting from Dalton, much of it has been discussed based on experimental evidence.*

IMPLICATIONS ON THE SOURCE DOMAINS

No theme of this analysis corresponds to any of the expected seven milestones of Dalton's achievement. Much of the finding is associated with the end result of the case study of Dalton's race in the HPS. Accordingly, two implications can be drawn. First, it does mean that the participants in such a system of teacher education are missing an understanding of an essential perspective of HPS, a chemical perspective on which the philosophy of chemistry (operational realism) was found. This is an important perspective that offers an alternatively sounding explanation of the very controversial issue of atomic ontology. Second, it implies that the participants were not able to learn from the professional race of those prominent scientists and philosophers such as Dalton.

Especially, the fact that the participants were able to only recall the ultimate findings of Dalton's quest implies that learners in such a system are able to only fragments or portions of conceptions. The knowledge from such fragmented pieces wouldn't enable learners to make sense of the atom, atomic theories, and related fundamental concepts. This will have unavoidable drawbacks on the future career and professional development of the prospective educators and chemists, especially in terms of creativity and innovativeness. Because we, in this regard, believe that much could have been learned from all the ups and downs - arguments, claims, debates, errors, mistakes, critiques, and comments - of the history of philosophy and science in general and Dalton's in particular. Recalling the "correct" and "wrong" postulates of Dalton's atomic theory wouldn't enable them real educators or scientists.

We also noted, as teacher-educators who have been teaching those courses in which the atom and related topics are discussed, a common pattern of striving to echo what is listed in the course materials. Therefore, the findings do also imply that the source domain of such thinking and interpretation could be associated with the curriculum. It could be a limitation of the curriculum with respect to the due emphasis on such case studies, perspectives, and contexts of HPS. This does also have an important shade on the classroom instruction of the topics as well as the thinking pattern and underlying source domains of the educators in the university and other teacher education institutions.

DISCUSSION

The literature in general shows that the curricula and instruction as well as the resulting sense of the atom lack or paid little concern to essential historical and philosophical contexts, approaches, and evidence [22] [13] [23] [15]. More specifically, [9] reported that the most

important milestones of Dalton's quantification of the atom were missing in the examined undergraduate chemistry students of the University of Sao Paulo, Brazil. More proportion of the responses (43%) was found to be associated with the proposition of atomic theory or model. Thus, our findings agree with that of [9]. But, the proportion in our case is much higher (80.30%). The finding on the quantification and experimental proof of the existence of the chemical atom remaining untouched at all does also correspond to both studies. But, the two studies differ in that the participants in the earlier case were able to address one more theme of Dalton's milestones, proposing a law on the behavior of gases. Another theme of participants' responses was also found in about 175 of the statements. The theme was entitled "vague or imprecise statements", in which issues such as proposing the ''plum pudding'' model, stating molecules being made of atoms and the likes, are sorted.

In general, this analysis indicated that the very chemical perspective of the atom and its theory are missing from the participants' thinking and interpretations. Besides, the whole historical and philosophical route of Dalton's quest, from the very first theory of mixed gases to the quantitative chemical atomic theory through the determination of atomic weight, is missing from the examined narratives. The findings, from this point of view, coincide with Rocke's claim of poor or little emphasis. The following is an excerpt quoted from the preface of his book (1984, XII).

> *Indeed, little recent work has been done on post-Daltonian chemical atomism, which is surprising considering the circumstance that atomism has formed the conceptual basis of chemical theory since Dalton's day.*

With respect to the second concern, source domains, and underlying associations, the resulting implications coincide roughly with those curriculum and related document analyses [14] [15]. The implications drawn so far could also overlap with the discussions and suggestions of [12] [22], and [9].

CONCLUSION AND SUGGESTION

We aimed in this study to figure out how much Dalton's race to his new philosophy of chemistry in general and chemical atomism, in particular, is worthy to the prospective teachers of Kotebe University of Education. The resulting transcripts were analyzed using HPS as a framework in which significant segments were identified, sorted, and discussed based on the seven milestones of the case study Dalton. As a result, one major and two minor themes were found and discussed in accordance with the aforementioned purpose. Unfortunately, all of them don't match any of the themes of the seven milestones. The major theme, proposing the first atomic theory, is associated, not with any of those milestones, but with the ultimate attainment of Dalton's quest. Neither is the minor sub-theme of the "ball atomic model". The remaining minor theme, relying on experimentation and corresponding evidence, rather corresponds with the professional quality and commitment of Dalton.

Moreover, even the portrayal in such a case of the major theme itself was found to be distorted. Because it lacks an essential chemical perspective of HPS in the emergence and application of the new philosophy of chemistry. Besides, some important contexts of Dalton's experimentations, analyses, and interpretations are still missing. Misjudging Dalton's postulates, such as the divisibility and continuity issues, were traced to be attributed to such lack of essential chemical perspective, historical, philosophical, and scientific contexts. The experimentations and analyses of the divisibility case, for example, were planned and conducted purely within the chemical contexts for the very chemical purpose. One could have noted that Dalton was referring, in one of its postulates, to the chemical divisibility. In that case, it is correct that the atom can no more chemically divided into smaller forms of substance or particles. Thus, is that the prospective teachers in such a system are able to

only fragments or portions of conceptions, which are practically hard to make sense of.

The study implies that the entire system of teacher education needs to be examined in detail in terms of its curriculum and classroom practice. In the long run, the curricula, educators', and candidate teachers' senses can be examined in detail with an HPS lens and explained in an informative way in association with those persistent naïve ideas and learning difficulties that the literature addresses as epistemological obstacles or learning impediments. In the short run, we believe that all the desired perspectives, contexts, and cases of HPS need to be raised and discussed with and by the educators of the university through any available mode. Intra and inter-institutional seminars, regular conferences, and workshops could be accordingly utilized. Communicating the findings of this study with the department head and educators that we had as a part of our commitment to quality and ethical codes itself is the basic one that can be considered as an implied suggestion.

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CONFLICT OF INTERESTS

We, the aforementioned authors, declare that neither the university nor the Bureau has any significant competing financial, professional, or institutional interests that might influence the publication of this article in this journal or somewhere else.

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