DIAGNOSING TEACHER TRAINEES' BASIC CONCEPTION OF THE STRUCTURE OF THE ATOM USING ATOMIC RADIUS QUESTIONNAIRE

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ABSTRACT

A proper understanding of the structure of the atom is fundamental in comprehending crucial concepts in chemistry. However, the concept of atom is abstract and complex in nature, conflicting with everyday experiences and common sense, and often requires high level of critical thinking skills to comprehend. This impedes most student from understanding and developing the right conception. Probing learners' conception of the atom using equally abstract and counterintuitive questionnaires may elicit responses produced out of memorization and rote learning. In this study, we explore the use of relatable concept to identify learners' misconception about the structure of the atom. Radius, a relatable concept, was used as a probe instrument to identify teacher trainees' misconception about the atom. Relevant questionnaires were constructed from how atomic radius is determined, and administered to second year teacher trainees to attempt. Responses were themed, coded and analyzed, enabling identification of level of conceptions, areas of misconception and possible sources of confusion. This study, therefore, provides an easy atomic structure conception instrument that can be applied outside or in-lesson to elicit relevant responses and gain a first-hand information on learners' conception about the atom.

Keywords: Misconception, atomic radius, teacher trainees, wave mechanical, atomic model.

INTRODUCTION AND THEORETICAL BACKGROUND

Chemistry is best understood using three levels of representations, namely, macroscopic, submicroscopic and symbolic representations (Trang et al., 2021). Macroscopic level deals with the description of phenomena encountered in everyday life (Koopman, 2017; Trang et al., 2021). The submicroscopic level explains particulate materials such as atoms, ions and molecules that make up the things encountered in everyday life (Hrast & Savec, 2017). Since particulate matter such as atoms, ions and molecules are not visible, the symbolic level uses chemical symbols, formulae and equations to help explain their nature and properties. These three levels of representation are therefore indispensable in the explanation and understanding of chemical phenomena.

The three levels of chemical representations as versatile as they may be sometimes fall short when it comes to the explanation of certain complex principles and processes in chemistry (Johnstone, 1991). Therefore, chemists have devised processes by which descriptions, called models, are developed to explain certain phenomena in chemistry (Coll, 2006; Harrison & De Jong, 2005; Justi & Gilbert, 2006). Simply put, models are object used as a pattern, example or standard. Models may be considered iconic, when it resembles its object but differ only in scale. Model can also be analogic, when it resembles its object in behaviour and form. However, majority of the models used in chemistry are abstract models (Coll, 2006). Take for instance, the periodic table of elements, though powerful and informative, it does not resemble the physical materials contained in it, nor does it portray their physical behaviour. Models have

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been built to teach a number of topics in chemistry including, chemical kinetics, thermodynamics, chemical equilibrium, reaction mechanisms and chemical bonding (Harrison & De Jong, 2005). However, majority of these models, unlike in other fields of science, are not self-explanatory. Most require expert interpretations or years of training to understand; this is a reason for the difficulty most students encounter in the study of chemistry.

The atomic model is indispensable for any student pursuing chemistry, or related field of science. Knowledge on atomic models is required at the early years of science education. The widely accepted atomic model, the wave mechanical model, was obtained after years of advanced experimentations. Therefore, understanding such model at early years of science education is challenging and most students resort to memorization, not truly understanding what it teaches about the atom and its implications. This widespread approach contributes to the common misconceptions about atomic models reported in the literature. Studies have reported several approaches to diagnose the level of students' misconception about the atom and also identify potential sources of these misconception. In a study by Park & Light, (2009), interviews on atomic structures were used to identify students misconception of the atom. Cokelez (2012) used questionnaires constructed from atom, ions and molecules to assess students' conception of atomic structure. In another study by Majid & Suyono (2018), written test of mental models and misconceptions were explored as diagnostic instrument to understand the level of students' conception of the atom. These approaches involve direct solicitation of students views of the structure of the atom. However, since the concept of the atom is abstract and complex, many students end up memorizing the atomic structures as depicted in models without grasping the underlying complexities.

If variety of diagnostic instruments is not introduced to understand students' conception of the atom, learners with good memorization skills can easily produce valid answers without solid understanding of the concept. In a study by Nyoman et.al (I Nyoman Suardana & I Made Kirna, 2017) which sought to analyze students learning difficulties on atomic structure, it was revealed that due to the abstract nature of the concept of atom, about 73% learn by memorization. It is therefore imperative to adopt varied methods that appeal to the different level of thinking to elicit responses on students' misconception about the atom. This research was guided by the research question;

Can the concept of radius be used to indirectly diagnose teacher trainees' level of conception about the structure of the atom?

Radius as applied in the context of the atom was explored as a diagnostic instrument to identify teacher trainees' misconception of the atom. Radius is a relatable concept which is applied in various fields of science, often pertaining to circles. Here, teacher trainees understanding of the definition of atomic radius was used as a probe to understand their conception of the wave mechanical model of the atom.

METHODOLOGY

Research design

The study uses a qualitative research design to understand student conception of the atom. Teacher trainees were provided with statement on how atomic radius is determined. From the statement, open ended questionnaires were constructed of which teacher trainees must attempt. The qualitative responses from students were themed, coded and analyzed descriptively to gain in-depth information about the level of misconception among students, and identify possible sources of these misconceptions.

Research Locale and Participants

The study was conducted at university of Education, Winneba in Ghana. It involved forty-two (42) teacher trainees, who are in their second year and pursuing a bachelor of science degree in Chemistry Education. The sample was purposive because this badge of teacher trainees had just taken a course (Introduction to inorganic chemistry) which have introduced them to the concept of the atoms and periodic properties. Thirty-three (33) of the participants were males whereas nine (9) were female.

Data collection and procedure

Data were gathered from the participant using an open-ended questionnaire. Respondents were provided with the scientific approach to determine the radius of the atom, which is a little different from conventional methods for determining the radius of the circle. From the scientific way of determining the radius of atom, three questionnaires were constructed. Respondents were to use the statement provided to attempt the questionnaires. The three questionnaires were designed in a way that requires right conception of the atom in order to provide the right answer. Each item consists of two parts, a YES/NO response and a justification or explanation of the choice. Table 1 summarizes how the probe instruments were framed.

Table 1. Questionnaire constructed from the determination of atomic radius to diagnose teacher trainees' conception of the atom.

Items	Description of the Items	Possible choices	
Atomic radius can be determined as half the distance between the nuclei of two identical atoms bonded together. From this statement, teacher trainees were asked to attempt the questionnaire below.			
1	From the statement provided- *why is atomic radius not determined from a single atom?*	Comment No comment	
			Justification/explanation
2	From the statement provided is *radius = diameter/2* applicable in the determination of the radius of an atom.	YES NO	Justification of the choice
3	From the statement provided given, do atoms have *precise boundary*?	YES NO	Justification of the choice

Data analyses

Responses from teacher trainees on the questionnaire were themed and coded into various headings. The themes were evaluated and quantified using percentages in order to understand their level of conception about the atom. The explanation and justification provided to support their answers to YES/NO questions where carefully studied to identify misconception teacher trainees hold on the structure of the atom.

RESULTS

Student trainees' level of conception of the electron cloud concept of the wave mechanical model of the atom

Table 2 illustrates teacher trainees' responses to questionnaire item 1. Respondents were asked "*why atomic radius is not determined from a single atom*", as depicted in the statement provided. This item sought to elicit teacher trainee's conception on why atomic radius is not determined from a single atom. Correct response to this item may require basic understanding of the wave mechanical model of the atom. Therefore, emphasis was placed on whether respondents will bring out ideas that highlight their conception of the wave mechanical model of the atom. Analysis of the responses as presented in Table 2 reveals that thirty-six (36) teacher trainees, representing 81 % of the sample population attempted the item, only 19 % did not make any comment. Out of those who responded, none could produce a right response to the item. Responses from the items were further analyzed and categorized under seven themes. The themes and percentage of students representing each category is presented in Table 2.

Table 2: Teacher trainees' response to item 1 in the questionnaire. Note: Unclear answers represent those responses which were incomplete and could be deemed wrong.

Theme from Responses	Percentages of teacher trainee (%)
1. Why is atomic radius is not determined from a single atom?	
...because atoms do not have shape	5 %
...because every atom has unique size	19 %
...because of the difference in subatomic particles	7 %
...because two atoms improve stability	7 %
...because it has to be determined from combination of radii	9 %
...because it is determined from the mean of atomic radii	5 %
Unclear answer	29 %
NO ATTEMPT	19 %

As illustrated in Table 2, students' response on *"why atomic radius is not determined from a single atom"* revolved around stability, shape, mean radius, subatomic particles and specificity of size; none of which is close to the expected response to the item. A comparison of the teacher trainees' responses to the expected shows their lack of understanding on the idea behind the scientific determination of the atomic radius.

Source of confusion on the wave mechanical model of the atom determined using atomic radius questionnaire

Table 3 illustrates teacher trainees' response to questionnaire item 2, which seeks to explore students' conception about the size and shape of the atom as illustrated by the wave mechanical model. In item 2, teacher trainees were asked "why diameter/2 is not used in the determination of the radius of the atom". This was to investigate how students perceive the shape of the atom. Radius is commonly used in association with circles, it will take a student who has developed proper conception of the wave mechanical model of the atom to know that atoms have complex shapes influenced by the probabilistic nature of electron positions. In reality, electron extents to infinity and there is no point where the probability of finding electron is zero, thus it is difficult to determine the diameter of the atom. Teacher trainees' response to item 2 shows that they lack understanding of the size and shape of the atom as majority stated that the atom is circular.

Table 3: Teacher trainees' response to item 2 of the questionnaire.

THEME FROM RESPONSES	PERCENTAGES (%)
2. Is radius = diameter/2 applicable to the determination of the radius of an atom. Explain your answer	
NO ATTEMPT	17 %
No *YES* or *NO* response	6 %
YES….	
...*because* half the diameter of a ***circle*** is radius.	24 %
...*because* atomic radius is determined from the ***average*** of two radii.	5 %
YES choice, without explanation	7 %
NO …	
…*because* atom do not have a diameter.	5 %
…*because* atomic number and nuclear charge determine the radius.	5 %
…*because* atomic radius is determined from the ***mean*** value of two radii.	14 %
… because atomic is determined from the distance between two atoms	17 %

As present in Table 3, 83 % of teacher trainees attempted item 2. Thirty six percent (36%) out of those who attempted the item responded YES, whereas 41% responded NO. Twenty four percent, 24 %, of the teacher trainees representing the majority, responded that radius = diameter/2 is applicable in the determination of the radius of the atom "because half the diameter of a circle is radius". Two direct extracts from transcripts of the teacher trainees' read "*Yes because the radius is the distance from the circumference to the center of the atom"* and *"It is applicable because shells of various elements are circle"*. These responses from majority of the teacher trainees are an indication that the teacher trainees are generalizing their understanding of radius as pertained to circles to the model of the atom. This suggests that the teacher trainees' have the perception that atoms are circular. Scientifically, atomic radius is not determined using the conventional diameter/2 approach as used for radius of a circle, because according to the wave mechanical model, atoms do not have a well-defined size, it is therefore impossible to know its boundary. However, the teacher trainees perceive the atom as circular with definite size and shape, making their understanding of the atom a misconception.

Diagnosing teacher trainees' misconception of the wave mechanical model of the atom using atomic radius questionnaire

Item 3 of the questionnaire seeks to solicit respondents' views on whether atoms have boundaries or not. The item was in two parts, the first part demands a YES or NO response, the second part requires a justification or explanation of the choice. As presented in Table 4, 71% of the respondents attempted the item, whereas 29 % did not. Thirty one percent, 31%, of the teacher trainees responded YES, whereas 40% responded NO. To gain a deeper insight into the response of item 3, their transcript was themed, and students' misconception were identified. From Table 4, 21% of teacher trainees, representing the majority responded that “yes, *atoms have precise boundary because it is surrounded by shells*”. Two direct extracts of respondents’ transcripts read “*Yes the precise boundary is called the shell in which electrons are located in it*”, and “*Yes each atom has a valence shell which represents its boundary*”. This is a misconception in that, an atom does not have a sharp, well-defined boundary like a solid object, it is illustrated to show regions where the probability of finding an electron is highest. As presented in Table 4, apart from 10 % who responded that “the region is not defined”, all the responded gave answers that reveal their misconception of the atom. Teacher trainees hold perception such as; atoms are circular; atoms have boundary; shells are boundary; and atoms have definite size.

Table 4: Teacher trainees’ response to questionnaire item 3.

THEME FROM RESPONSES	PERCENTAGES (%)
3. Does the atom have a precise boundary? Explain your answer	
NO ATTEMPT	29 %
YES….	
...*because* it is surrounded by shells.	**21 %**
...*because* the atoms precise boundary is the nucleus.	5 %
YES choice, without any explanation	5 %
NO …	
…*because* the shape and size vary for different atoms.	12 %
…*because* the region is not defined.	10 %
…*because* electron gain or loss can change the precise boundary.	5 %
NO choice, without any explanation	13 %

DISCUSSION

Relatable concepts are ideas that connect new information to something which is familiar to the learner's existing knowledge. They serve as bridges between the unknown and the known, making learning more effective and enables the understanding of abstract or challenging content (Lindsay, 2011; Mvududu & Kanyongo, 2011; Wubbels, 1992). Relatable concepts therefore facilitate learning and comprehension by aiding understanding, decreasing cognitive load, enhancing retention and fostering critical thinking (Bolkan & Goodboy, 2020; Brachten et al., 2020; Jordan et al., 2020; Richland et al., 2013). This is in line with the constructivists theory which argues that learners learn by building on already existing ideas (Kalpana, 2014). These ideas or *schemas* are built at the early stages of education as the learner interacts with the environment. When learners are able to relate or link what they are learning to the concept they already know, active learning occurs. Not only does relatable concepts aid in the understanding of concepts, but also helps to diagnose learners’ misconceptions (Üce & Ceyhan, 2019). By carefully monitoring how learners align new ideas to already learned concepts, possible misconceptions can be identified.

In the context of the atom, due to the complex and counter intuitiveness nature of the concepts (Kiray, 2016; Taber, 2003), using relatable concepts as a diagnostic tool, not only reveals learners misconceptions but enable the provision of targeted intervention and correction. In this study, learners’ misconception of the structure of the atom was identified using radius as a relatable concept. Radius is a generally a known term across the various field of science, and it is commonly defined as half the diameter of a circle, especially in basic mathematics. A careful monitoring of how learners apply their already learned concept about radius to the case of the atom can enable the identification of incorrect association and misaligned analogies, hence pinpointing learners' misconception about the structure of the atom.

To accurately understand and identify learners' misconception about the atom using the concept of atomic radius determination, emphases were placed on how it helped to visualize the misconception, and recognize incorrect association and misaligned analogies about the atom. Questionnaire item 2 enabled the visualization of learners' misconception about the atom. Because radius is a relatable, teacher trainees have already created a mental picture about the concepts behind its determination. This served as a yardstick to paint a concrete picture about their misconception. It could be visualized that learners perceive the atom as circular, a common explanation for which majority of the teacher trainee gave to questionnaire item 2. This is a misconception because the wave-mechanical model of the atom tells that the atom is not circular because the electrons do not orbit around the nucleus in a circular path, instead, they exist in regions called orbitals, which have various shape like spherical (a three-dimensional representation), dumbbell and other complex geometries.

In addition, using radius as relatable concepts unearth misaligned association and incorrect analogies which are the foundation of their misconception of the atom. Questionnaires items 1 and 3 helped to recognize incorrect associations that results in the wrong conception about the structure of the atom. It was identified that learners associate *shells with boundaries*, *energy levels with boundary of the atom,* changes in atomic radius due to electron gain or loss as an impression of the boundary of the atom.

CONCLUSION

The study concludes that the concept of radius can be used as an instrument to identify teacher trainees' conception, and diagnose their misconception about the structure of the atom. It was evident that radius as a relatable concept can easily help gain meaningful information devoid of memorization and rote learning from teacher trainees. It could also serve as indirect and simple questionnaire, contrary to the conventional, complex and counterintuitive questionnaire constructed directly from the concept of the atom to identify an diagnose learners' misconception about the structure of the atom. Various misconceptions teacher trainees hold about the structure of the atom were identified. These misconceptions revolved around the size and shape of the atom. An improper conception of these aspects of the atom can impede the comprehension of most topics in chemistry. Misconceptions such as 'atom is circular', 'shells denote the precise boundary of atoms' and 'atoms have definite size' were recorded. The use the concept of radius, thus, provides an easy atomic structure conception instrument that can be utilized inside or outside the classroom to gain a first-hand information on learners' conception about the atom.

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