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Misconception Diagnostic in Quantum Number Materials and Electron Configuration

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ABSTRACT

The purpose of this study is to design a four-tier diagnostic test instrument for electron configurations and quantum numbers that can be used to analyze misconceptions. The four-level diagnostic test instrument assesses students' conceptual comprehension of a subject matter. The four-tier test has four levels: knowledge, confidence in completing questions, reasons for answering questions, and confidence in giving reasons. This study used a descriptive qualitative method with the stages of analyzing the problem, collecting data, product design, validating the design, and conducting instrument trials. The results showed that the designed diagnostic instruments were both feasible and reliable. Instrument test results indicate that indicator a) determines the magnitude of the four quantum numbers (n,ℓ,mℓ, ms) in an orbital; b) identify the characteristics and functions of the azimuth quantum number (ℓ); c) determine the spin magnetic quantum number (ms) of the electron in the orbital; and d) determine the spin magnetic quantum number (ms) of a single electron in an orbital, which is the most misunderstood.

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1. INTRODUCTION

Science is a subject that has an important role in education. Science can equip students to face future challenges. The main goal of learning science is for students to experience changes in behavior and understand principles, laws, and concepts broadly and deeply [1]; [2]. For this reason, a teacher has a very important influence in creating a conducive, creative and fun learning atmosphere so that students are impressed with the lessons they receive [3]. In addition, a teacher should convey subject matter according to the right concept so that they don't just know, but really understand the material according to the right concept. A good understanding of concepts will improve thinking skills and good problem solving, thereby reducing the occurrence of misunderstandings in understanding concepts [4].

One of the obstacles faced by students in understanding a concept is that students cannot properly accept the concepts that have been taught by the teacher or are often called misconceptions [5]. Misconceptions can be in the form of mistakes in understanding the initial concept or mistakes in the incorrect relationship between concepts, ideas, and views that are also inappropriate [6]. Students are said to experience misconceptions if students make repeated mistakes in the same form and type of questions [7]

The misconceptions experienced by students resulted in planned learning objectives that were not optimally achieved [8]. Therefore, it is necessary to analyze misconceptions so that the learning objectives can be achieved optimally. Misconceptions generally occur because the material being studied is invisible (abstract). One material that can cause misconceptions is the concept of atoms related to the electron configurations.

Electron configuration is a submatter in the discussion of atoms. Atoms are particles that cannot be seen even with the most advanced microscopes because atoms are smaller than visible light waves; therefore,

studying atoms requires high imagination. Atomic material is one of the materials that is considered difficult for students because the material presented cannot be seen or experienced by students directly [9] As a result, students have different interpretations in understanding the concepts or theories learned with their true [10]; [11]; [12]. Interpretations that deviate from the true meaning result in misconceptions.

Misconceptions experienced by students should be identified immediately so that remedial teaching can be carried out immediately, especially in the sub-matter that has the highest misconceptions. Through remediation learning, misconceptions can be straightened into correct concepts. Misconceptions are caused by personal mistakes made by someone. [13] grouped several errors made by students, including a) slip, which is a mistake caused by being in a hurry when working on questions; b) conceptual errors, that is, lack of understanding of concepts due to not mastering basic facts, concepts, and skills; and c) procedural errors, that is, students understand concepts, but cannot apply them to problems, so students use concepts but do not understand the essence of what he did.

Misconceptions can be identified using diagnostic test instruments [14]. A diagnostic test is conducted to see students' weaknesses in understanding a concept so that appropriate treatment can be formulated. Diagnostic tests can detect student misconceptions in each indicator [15]. The four-tier test is an extension of the three-tier test, which combines students' beliefs in providing answer arguments [16]. The four-tier test can identify misconceptions experienced by students in more detail and depth and can determine question indicators that require further emphasis [17]. Through diagnostic tests, educators can carry out remedial teaching and tests to achieve the ultimate goal of learning.

2. METHOD

This study uses a descriptive qualitative approach for data collection, processing, and analysis, as well as drawing conclusions [18]. The four-tier test instrument was tested on 29 immersion (first) grade 10 students in Madrasah Aliyah Hasyim Asy'ari Bangsri. The stages of developing this instrument are a) reviewing the syllabus related to material where there may be misconceptions in learning, b) limiting the study of student misconceptions through observation and interviews, then determining the material to be developed for the misconception diagnostic test instrument, c) designing/developing four-tier diagnostic test questions, d) performing instrument validation, and e) conducting instrument trials. The grouping of misconception criteria consists of four criteria: 1) misconception, 2) not understanding the concept, 3) error, and 4) understanding the concept [19], [20], as presented in Table 1.

Table 1. Analysis of combinations of answers at the *four tiers*

Category	Answer	Believed Answer	Reason	Believed reason
Misconception	T	S	F	S
	T	N	F	S
	F	S	F	S
	F	N	F	S
Don't understand the concept	T	S	T	N
	T	S	F	N
	T	N	T	S
	T	N	T	N
	T	N	F	N
	F	S	T	N
	F	S	F	N
	F	N	T	N
	F	N	F	N
Error	F	S	T	S
	F	N	T	S
Understand the concept	T	S	T	S

Note: T = True; F = False; S = Sure; N = Not sure

Data collection techniques were carried out by observing, testing, and interviewing the sample. Data collection was carried out by giving validated diagnostic questions to respondents, in this case, class 10 IPA. The examples of diagnostic questions given to students can be seen in Figures 1 and 2.

Figure 1. Snippet of four tier diagnostic questions

The four possible quantum numbers for the electron in the highest energy level of the Cr atom (atomic number 24) are...

$n = 4, \ell = 0, m_\ell = 0, m_s = + ½$
$n = 4, \ell = 0, m_\ell = 0, m_s = + ½$ atau $– ½$
$n = 3, \ell = 2, m_\ell = +2, m_s = + ½$
$n = 3, \ell = 2, m_\ell = -2, m_s = + ½$ atau $– ½$

Are you sure about your choice?
A. Sure
B. Not sure

The reason for answering this question is...
1. The outer electrons are in the 3*d* orbital, so the proper quantum number series is $n = 3, \ell = 2, m_\ell = +2, m_s = + ½$.
2. The outer electrons are in the 3*d* orbital, so the proper quantum number series is $n = 3, \ell = 2, m_\ell = -2, m_s = + ½$ or $– ½$.
3. The outer electrons are in the 4*s* orbital, so the proper quantum number series is $n = 4, \ell = 0, m_\ell = 0, m_s = + ½$.
4. The outer electrons are in the 4*s* orbital, so the proper quantum number series is $n = 4, \ell = 0, m_\ell = 0, m_s = + ½$ or $– ½$.

Are you sure about your choice?
A. Sure
B. Not sure

Figure 2. Snippet of four tier diagnostic questions

If the electron spin symbol used is ↑ or ↓, then the most appropriate way of arranging the electrons in the $2p^3$ orbital is

Are you sure about your choice?
A. Sure
B. Not sure

The reason for answering this question is...
1. the three electrons in the 2*p* orbital will occupy the orbital with the same spin direction until it is half full, maybe all of them have $m_s = + ½$ or all of them have $m_s = - ½$.
2. The three electrons in the 2*p* orbital will occupy the orbital with the same spin direction until it is half full, so all of them have a clockwise spin first ($m_s = + ½$).
3. The three electrons in the 2*p* orbital will occupy an orbital with the same spin direction until it is half full, so all of them have a counterclockwise spin first ($m_s = - ½$).

Are you sure about your choice?
A. Sure
B. Not sure

The data analysis technique used is a combination analysis of the four-tier answers according to Gurel as presented in Table 1.

3. RESULTS AND DISCUSSION

The research begins with a literature review of the syllabus and identification of materials or indicators in chemistry that make it possible for misconceptions to occur. Based on the analysis of the material, it was identified that material that allows for misconceptions to occur cannot be explained in real or visible (abstract) terms. This material is the concept of atomic structure, including electron configurations and quantum numbers [21]; [22]; the concept of solution [23]; [24]; buffer solution [25]; chemical equilibrium [26]; hydrocarbons [27]; chemical bonds [28]; [29]; [28] explained that students' difficulties in learning chemical bonding materials are characteristics of chemical concepts that are not contextual, causing students to have misconceptions.

Making changes to students who experience misconceptions is quite difficult, so it needs a process and practice so that students really understand the material well. This is in line with the opinion [30], which states that learning the concept of quantum numbers requires complex understanding and structured training. Based on a literature review or theory, materials that often cause misconceptions can be identified. Next, we determined one of the materials to be analyzed for misconceptions. The materials chosen are the quantum number and electron configuration. The choice of this material is due to the fact that the material of quantum numbers and electron configurations is abstract, so that it requires a more detailed and real explanation.

The next stage was to design/compile a diagnostic test instrument based on predetermined indicators. Draft I (initial) is a matter of description, with a total of 35 questions that have been tested for validity and reliability. The descriptive questions that had been prepared were then tested on 29 students in grade 10 immersion. The answers obtained from the description test were used as an alternative choice of answers to the questions, so draft II, called the four-tier multiple-choice diagnostic test questions, consisted of 30 questions. The questions were validated by five expert validators. The results of validating the questions using the Content Validity Ratio (CVR) are presented in Table 2.

Table 2. Validation results of four tier multiple choice questions

Expert Code	Number of Assessment/Items of assessment						
	1	2	3			30	
K	1	1	1	…	…	1	
L	1	1	1	…	…	1	
M	1	1	1	…	…	1	
N	1	1	1	…	…	1	
O	1	1	1	…	…	1	
ne	5	5	5	…	…	5	
N	5	5	5	…	…	5	
CVR	1,00	1,00	1,00	…		…	1,00
CVI	1,00						

Based on expert validation, 30 questions were declared valid/feasible to use, but there were several inputs from experts, including those related to language and symbol consistency. The improvements (revisions) based on expert input on the four tiers multiple choice question instruments are presented in Table 3.

Table 3. Instrument revision of four tier multiple choice questions

No.	Types of revision	Before revision	After revision
1	Question sentence	If there is an A orbital that has the following specifications:	Here are how many statements of an orbital:
2	Symbol consistency.	Which statement indicates the magnetic quantum number (*m*) of the orbital?	The statement that shows the magnetic quantum number ($m\ell$) is...
3	Question sentences and consistency of terms, symbols.	Which description gives the spin quantum number (*s*) of the orbital?	The statement that shows the spin magnetic quantum number (*ms*) is...
8	Sentence reason answer	$n = 4$, $\ell = 1$ states the 4*p* orbital and the first electron occupies one type of *p* orbital which	$n = 4$, $\ell = 1$ represents the 4*p* orbital and the first electron is free to

No.	Types of revision	Before revision	After revision
		has the same or the same energy level.	choose to occupy one of the *p* orbitals.
18	Sentence reason answer	According to the Pauli principle, in one orbital two electrons may not have the same spin.	According to the Pauli principle, in one orbital two electrons cannot have the same spin.

The next stage involved test questions. Questions that were declared feasible were then tested in class 10 Science with a total of 36 students. Not all questions were tested, but only 21 out of 30 four-tier multiple-choice questions represented quantum number and electron configuration indicators. This is because it makes it easier to determine the profile of misconceptions and efficiency of research time.

Based on the results of the misconception test with four tier multiple choice diagnostic questions in class 10 IPA, it can be identified that there are four indicators that have the most misconceptions, namely the indicators: a) determining the magnitude of the four quantum numbers (n,ℓ,mℓ,ms) in a orbitals; b) identify the characteristics and functions of the azimuth quantum number (ℓ); c) determine the spin magnetic quantum number (ms) of the electron in the orbital; and d) determine the magnetic quantum number of spin (s) of a single electron in an orbital.

The indicators that tend to have the most misconceptions are due to several reasons, including that most students believe that the filling of the p and d orbitals must start from the far-left box and must begin with an upward arrow first, so that many students experience misconceptions about Hund's rule. Students also experienced misconceptions when asked to determine the magnetic quantum number of the electron spin in the orbital or to determine the value of the four quantum numbers. This is in accordance with the research of [21], which found a high misconception of the orbital concept in class XI MIPA students of SMAN 5 Bima.

In this study, it was found that 75% of the students had misconceptions about the meaning of the magnetic quantum number; only 3% understood the concept of the meaning of the magnetic quantum number, which shows the orientation of the orbitals on the Cartesian x, y, and z axes. This student's opinion is the same as the results of previous research [31], which states that the magnetic quantum number values -1, 0, +1 indicate the numbering order of the x, y, and z orbital spaces. Based on interviews with students, it is known that the subject teacher never explains the meaning of magnetic quantum numbers, and students do not have book references that have knowledge about it.

None of the students understood the concept of determining the magnetic spin quantum number of 2p3 orbital. This is because all students think that filling the 2p3 orbital requires all arrows to be drawn up first, and all have ms = + ½. According to Greenwood (1968) it is not a certainty that a single electron must have a spin magnetic quantum number (ms) = + ½, the truth is that it is a possibility, perhaps worth + ½ or – ½.

Around 71% of the students experienced misconceptions when determining the 28Ni valence electrons. This is because many students think that the valence electrons of 28Ni are in the 4s2 3d8 orbital and not in 3d8 4s2. Students experienced 63% misconceptions about the electron configurations and energy levels. This is because students believe that electrons in the highest energy level in atoms 26Fe are in the 3d orbitals. The results of the study [32] also show students' misconceptions that the energy level of the 4s subshell is lower than that of the 3d subshell. [33] stated that there are often misconceptions about electron configurations regarding the Aufbau method and first ionization energy for transition elements. Many researchers claim that the energy of the 3p orbital is higher than that of the 4s orbital. Many chemistry reference books make mistakes when discussing the relative energies of the 4s and 3d orbitals [34].

The results of the electron configuration misconception diagnostic test showed that 38% had misconceptions, 23% understood the concept, 17% had errors, and 22% understood the concept. According to some students, if atoms 25Mn release electrons 25Mn to Mn2+ form ions, then the electrons released come from the 3d orbitals because the 25Mn valence electrons are 4s2 3d5; thus, the electrons released are as many as two electrons in the 3d orbitals as many as 2 electrons. Many students make mistakes when working on the application of electron configurations for neutral atoms and ions; therefore, they cannot determine the orbital diagram, element location, and molecular shape correctly [35]. Misconception problems generally occur because of failure of the accommodation process [36]. Failure to change the wrong concept is caused by failure of the accommodation process in the student's cognitive structure [36].

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To minimize students' misconceptions, teachers should conduct remedial teaching activities on indicators that have the highest levels of misconceptions. In addition, the teacher should provide learning with a more interesting strategy by packaging material that is not (abstract) into material that can be seen by way of modeling, animation, and others. Further research should focus on the validity and reliability of this four-tier diagnostic test instrument.

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