MINIMIZANDO O ERRO DE CONCEPÇÃO DA ENERGIA DE IONIZAÇÃO POR TESTE DE DIAGNÓSTICO DE TRÊS NÍVEIS

MINIMIZING MISCONCEPTION OF IONIZATION ENERGY THROUGH THREE-TIER DIAGNOSTIC TEST

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RESUMO

Pesquisas sobre concepção e equívocos sobre tópicos específicos no ensino de ciências ainda são vistas entre os pesquisadores. A energia de ionização é um conceito que pode gerar compreensão (ou incompreensão) para os alunos. Portanto, este estudo teve como objetivo investigar a compreensão da energia de ionização entre estudantes do ensino médio. No total, 118 estudantes da East Java-Indonesia foram convidados para um teste online de Ionização de Diagnóstico Energético * Modificação (IEDI * M) através de um estudo de levantamento. O IEDI * M consistia em 12 opções de múltipla escolha com itens de três níveis. Os achados mapearam os principais equívocos sobre a energia de ionização, especialmente para o Grupo 1, Grupo 2, Período 2 e Período 3 estabelecidos no sistema periódico. Ao usar testes de três níveis, os percentuais de conceitos errados diminuíram de um nível para dois níveis e de de dois para três.

Palavras-chave: *teste de diagnóstico, energia de ionização, teste de três níveis*.

ABSTRACT

Research about conception and misconception of specific topics in science education is still sightseen among researchers. Ionization energy is one concept that possible generate mis(understanding) for students. Therefore, this study aimed to investigate the understanding of ionization energy among high school students. Totally, 118 students from East Java-Indonesia were invited to an online-Ionization Energy Diagnostic*Modification (IEDI*M) test through survey study. IEDI*M consisted of 12 multiple choices with three-tier items. The findings mapped the main misconceptions of ionization energy, especially for Group 1, Group 2, Period 2, and Period 3 established on the periodic system. By using three-tier tests, the percentages of misconceptions decreased from one-tier to two-tier and from two-tier to three-tier levels.

Keywords: *diagnostic test, ionization energy, three-tier test.*

INTRODUCTION

Previous researchers have used various terms (i.e. alternative conceptions, children's ideas, mental models, misconceptions, etc.) in representing students' conception of scientific concepts (Suprapto, Syahrul, Agustihana, Pertiwi, & Ku, 2016). However, the terms 'alternative conceptions' and 'misconceptions' have used widely in the world. For special cases, the term 'misconceptions' is more appropriately used (i.e. students' problems about science conception and how to remediate the problem). Therefore, the term 'misconceptions' is used in this study. Study about conceptions of students about specific topic is useful for predicting their self-efficacy for learning (Suprapto, Chang, & Ku, 2017) and enhancing conceptual schemes (Toshev, 2012).

Some techniques can be used for diagnosing misconceptions in science education: tests (multiple-choice tests, two-tier tests, three-tier tests, four-tier tests, open-ended tests,), concept maps, mind maps, analogy, interviews, and combination among those methods (Suprapto et al., 2016) and visualization-representation (Sunyono, Tania, & Saputra, 2016). Each method has the advantages and the limitations. In 1990s, multiple choice tests (MCT) was initially used (i.e. Force Concept Inventory and Mechanical Baseline Test) and promoted by Hestenes and his team (Hestenes & Wells, 1992; Hestenes, Wells, & Swackhamer, 1992). However, the main drawback of MCT is it doesn't convey deep enough investigation into students' ideas. Two-tier tests can minimize the problem of MCT, however, they can't determine the proportion of the misconceptions due to lack of knowledge. As a solution, three-tier multiple choice tests hold the strengths provided by two-tier and determine the answers given to the first two-tier are due to misconception (MSC), false positive (FP), false negative (FN), or a lack of knowledge (LK).

By providing three-tier tests, researchers enable to address the aforementioned limitation by adding an extra tier that necessitate students to state the level of confidence about their answers to the first two-tier (Caleon & Subramaniam, 2010; Peşman & Eryılmaz, 2010). In fact, there are only a few studies in science education on the development and implementation of three-tier tests, such as the wave diagnostic instrument-WADI (Peşman & Eryılmaz, 2010) and three-tier circular motion test (Kızılcık & Güneş, 2011). Specifically in chemistry, the popular three-tier tests are three-tier acids and bases test (Cetin-Dindar & Geban, 2011) and states of matter diagnostic test (Kirbulut & Geban, 2014).

As a set for triggering three-tier test, there were some two-tier diagnostic tests, for instance: ionization energy diagnostic instrument-IEDI (Tan, Taber, Goh, & Chia, 2005), two–tier chemical concept tests (Chiu, 2007), etc. This study endeavors the IEDI with three-tier diagnostic test. The test is based on the work of Tan *et al* (2005). In other words, this study reviews and follows up Tan *et al* (2005)'s study. Ionization energy is one of the essential subjects in the 10th grade Indonesian chemistry curriculum. It includes in fundamental concept of physical atomic properties and relates to atomic radius, electron affinity, and electronegativity, which are conceptually helpful in understanding the characteristics of each atom. Research on this concept has attracted considerable research interest over the last decade (e.g., Lang & Smith, 2003; Taber, 2003; Tan, et al., 2005; Tan & Taber, 2011). In Tan *et al* (2005)'s study, the focus of investigation was A-level students in Singapore, they explored students' understanding of ionization energies trend across Period 3. However, no study investigated the understanding of ionization energy with three-tier test among high school students (HSSs). Therefore, this study pronounces the solicitation of a three-tier diagnostic test to measure high school students understanding of ionization energy concepts.

Investigating the conception of ionization energy among HSSs could explain the main sources of misconception. This study aimed to investigate the understanding of ionization energy among high school students. To make this research more focused, then, the research questions (RQs) that guided this study are:

1. What are the common misconceptions performed by HSSs about ionization energy?
2. To what extent the effectiveness of using three-tier test comparing to two-tier test and one-tier test in minimizing misconceptions of ionization energy?

MATERIALS AND METHODS

The modification of IEDI instrument and Participants

The study utilized an online survey study through three-tier test. The instrument was a mix of the right technical words and some specific logical analysis, enhance scientific thinking process and improve understanding of the true meaning of the terms used (Thimmappa, 2011), in this case of ionization energy. The development of the IEDI*M instrument based on the previous works (i.e. Taber & Tan, 2007; Tan et al., 2005; Tan & Taber, 2011). Originally, the instrument consisted of 10 two-tier items with the composition of each tier as shown as Table 1 and explored students' understanding of the trend of ionization energies across Period 3 only. After holding permission for research purpose, the Indonesian version was developed. The modification was accomplished due to specific reason: for achieving the whole picture of the conception of ionization energy across Group 1, Group 2, Period 2, and Period 3 on periodic system. Finally, 12 three-tier items were used in the study. The test was administered through an online test via Google Docs1). Meanwhile, the distribution of participants is illustrated on Table 2.

Data Analysis

The IEDI*M responses were categories into six levels (see Table 3): i) Scientific Conception (SC), ii) False Positive (FP), iii) False Negative (FN), iv) Misconception (MSC), v) Lack of Knowledge–Guessing (LKg), and vi) Lack of Knowledge–Deficiency (LKd). This study follows the rule: "the percentage of student responses >20% for the non-scientific options be defined as typical alternative responses" (Peterson, Treagust, & Gannett, 1989).

RESULTS AND DISCUSSION:

Since Mendeleev's periodic table was released previously, analyzing to the classical view on the periodicity of the chemical elements: ionization energy, electronegativity, radioactivity, isotope, elements transmutation, quantum mechanical interpretation in the periodicity became priorities (Toshev, 2010). On the other hand, "the strengthening from the IUPAC recommendations related to the names and symbols of chemical elements, approved collective names of like elements, the system for describing of ionic charges and oxidation numbers as well as some new definitions opened new challenge" (Zahariev, 2015). When a new element is discovered, then accepted by a joint IUPAC-IUPAP (International Union of Pure and Applied Physics), the researchers are invited to propose a name and a symbol to the IUPAC Inorganic Chemistry Division (Atanassova, 2015). Then, the next discussion here is the main misconception of ionization energy, especially for Group 1, Group 2, Period 2, and Period 3 established on the periodic system, which is included some elements: Sodium (Na), Magnesium (Mg), Aluminum (Al), Silicon (Si), Phosphorus (P), Sulphur (S), Lithium (Li), Beryllium (Be), and Boron (B).

The distribution of understanding about ionization energy

Table 4 demonstrates the percentages of scientific conception, false positive, false negative, misconception, lack of knowledge-guessing, and lack of knowledge-deficiency among high school students. When the items were checked for scientific conceptions, it was found that the majority percentages indicated above 20%, except for item 6, item 9, and item 11. Item 6 is related to the comparison of the first ionization energy between magnesium (Group 2) and aluminum (Group 13). When the items were confronted to false positives, it was found that all participants performed the percentages above 20% for item 2, 4, 5, 7, 8, 9, 10, and 11. In contrast, for false negatives, it was found that all the items, except for item 6, were below 20%.

Turning to the misconceptions, it was found that the performance of high school students to all items above 20%, except for item 2, 4, and 5. For example, item 9 assessed the comparison of the first ionization energy between phosphorus and sulphur (period 3). The correct answer for the first tier is "the first ionization energy of phosphorus is greater than that of sulphur". The reasoning for the second tier is "the effect of an increase in nuclear charge in sulphur is less than the repulsion between its 3p electrons". Considering this item, it was seen that most of the participants chose one of the wrong alternatives – "the first ionization energy of phosphorus is less than that of sulphur" for the first tier and "the effect of an increase in nuclear charge in sulphur is greater than the repulsion between its 3p electrons” for the second tier. In addition, some participants chose either ”more energy is required to overcome the attraction between the paired 3p electrons in sulphur” or ”3p electrons of sulphur are further away from the nucleus compared to that of phosphorus” for their reasoning in the second tier.

Item 12 assessed the comparison of the first ionization energy between beryllium and boron (Period 2). The correct answer for the first tier is “the first ionization energy of beryllium is greater than that of boron”. The reasoning for the second tier is ”the 2p electron of boron has a lower penetrating power than the 2s electrons therefore it outweighing the increase in nuclear charge”. It was grasped that the most participants chose one of the wrong alternative options–”the first ionization energy of beryllium is less than that of boron” for the first tier and ”the 2s electron of beryllium has a lower penetrating power than the 1s electrons therefore it outweighing the increase in nuclear charge” for the second tier. In addition, some participants chose either ”the 2p electrons of boron are further away from the nucleus compared to that of beryllium” or ”the effect of an increase in nuclear charge in boron is less than the repulsion between its 2p electrons” for their reasoning in the second tier. Furthermore, the following section is discussed the explanation of some items as examples (item 6, 7, 11 and 12).

The comparison of the first ionization energy among sodium, magnesium, and aluminum (item 6 and item 7)

Item 6: *Bagaimana energi ionisasi pertama dari Magnesium ($1s^2$ $2s^2$ $2p^6$ $3s^2$) dibanding dengan Aluminium ($1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^1$)?*

A. Energi ionisasi pertama Magnesium lebih besar dari Aluminium.
B. Energi ionisasi pertama Magnesium lebih kecil dari Aluminium.

Alasan:

(1) Pelepasan sebuah elektron akan mengganggu kestabilan orbital 3s Magnesium yang terisi penuh.
(2) Elektron pada orbital 3p Aluminium berada lebih jauh dari inti dibandingkan dengan jarak elektron pada orbital 3s Magnesium.
(3) Pengaruh peningkatan pemuatan inti pada Aluminium lebih besar dari pada gaya tolak menolak antar elektron pada kulit terluarnya.
(4) Pengaruh peningkatan pemuatan inti pada Aluminium lebih kecil dari gaya tolak menolak antar elektron pada kulit terluarnya.

Keyakinan:
a Yakin
b Tidak Yakin

In the context of item 6, students performed only 3.39% of scientific conception. The most misconception among them is the combination of phenomena: “The first ionization energy of magnesium is greater than that of aluminum” with the reasoning ”the 3p electron of aluminum is further from the nucleus compared to the 3s electrons of magnesium” (22.03%). In addition, there was another combination (34.75%): ”the first ionization energy of magnesium is less than that of aluminum”, with the reasoning ”the effect of an increase in nuclear charge in aluminum is greater than the repulsion between the electrons in its outermost shell”.

Item 7: *Bagaimana kamu memperkirakan energi ionisasi pertama dari Natrium ($1s^2$ $2s^2$ $2p^6$ $3s^1$) jika dibandingkan dengan Aluminium ($1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^1$)?*

A. Energi ionisasi pertama dari Natrium lebih besar dari pada Aluminium.
B. Energi ionisasi pertama dari Natrium lebih kecil dari pada Aluminium.

Alasan:

(1) Aluminium akan mencapai keadaan penuh pada sub kulit 3s jika sebuah elektron dilepaskan.
(2) Natrium akan mencapai kestabilan oktet pada konfigurasi bila sebuah elektron dilepaskan.
(3) Elektron pada orbital 3p dari Aluminium lebih jauh dari inti dibandingkan dengan elektron pada orbital 3s dari Natrium.
(4) Efek peningkatan pemuatan inti dalam Aluminium lebih besar dari pada melindungi elektron pada orbital 3p oleh elektron pada orbital 3s.

Keyakinan:
a Yakin
b Tidak Yakin

In the context of item 7, HSSs showed above 20% of scientific conception. The correct answer for the first tier is “the first ionization energy of sodium is less than that of aluminum”. The reasoning for the second tier is “the effect of an increase in nuclear charge in aluminum is greater than the shielding of the 3p electron by the 3s electrons". The most misconception among them are "the first ionization energy of sodium is less than that of aluminum" due to "the 3p electron of aluminum is further away from the nucleus compared to the 3s electron of sodium" – (28.81%). However, students also varied in their reasoning: aluminum will attain a fully-filled 3s sub-shell if an electron is removed (20.34%) and sodium will achieve a stable octet configuration if an electron is removed (22.03%). Some misconceptions aforementioned were called relation-based reasoning. This result corroborated the studies conducted by Tan et al. (2008) and Tan & Taber (2011).

The comparison of the first ionization energy between lithium and sodium (item 11)

For item 11, there were some conceptions among students either "the first ionization energy of lithium is greater than that of sodium due to more energy is required to overcome the attraction between the paired 2s electrons in lithium" or "the 3s electrons of sodium are further away from the nucleus compared to that 2s of lithium". In addition, some participants assumed that "the first ionization energy of lithium is less than that of sodium" due to "more energy is required to overcome the attraction between the paired 2s electrons in lithium".

Item 11: *Lithium dan Natrium berada pada Golongan 1. Bagaimana kamu memprediksikan energi ionisasi pertama dari Lithium ($1s^2$ $2s^1$) dibandingkan dengan Natrium ($1s^2$ $2s^2$ $2p^6$ $3s^1$)?*

A. Energi ionisasi pertama dari Lithium lebih besar dari Natrium.

B. Energi ionisasi pertama dari Lithium lebih kecil dari Natrium.

Alasan:

(1) Lebih banyak energi yang diperlukan untuk mengatasi gaya tarik menarik antar pasangan 2s elektron dalam Lithium.

(2) Jarak subkulit 3s pada Natrium lebih besar dari pada subkulit 2s pada Lithium.

(3) Efek peningkatan muatan inti Lithium lebih besar daripada gaya tolak di anatara elektron- elektron pada orbital 2s tersebut.

(4) Efek melindungi elektron pada subkulit yang lebih dalam pada Lithium yang lebih besar dari pada efek peningkatan pemuatan inti.

Keyakinan:

a Yakin

b Tidak Yakin

❖ **Item 12:** *Bagaimana kamu memprediksikan energi ionisasi pertama dari Beryllium ($1s^2$ $2s^2$) dibandingkan dengan Boron ($1s^2$ $2s^2$ $2p^1$)?*

A. Energi ionisasi pertama dari Beryllium lebih besar dari Boron.

B. Energi ionisasi pertama dari Beryllium lebih kecil dari Boron.

Alasan:

(1) Elektron pada orbital 2p pada Boron memiliki kekuatan penetrasi yang lebih lemah dari pada elektron pada orbital 2s sehingga lebih berat dalam peningkatan pemuatan inti.

(2) Elektron pada orbital 2s pada Beryllium memiliki kekuatan penetrasi yang lebih lemah dari pada elektron pada orbital 1s sehingga lebih berat dalam peningkatan pemuatan inti.

(3) Elektron pada orbital 2p pada Boron lebih jauh dari inti dibandingkan dengan Beryllium.

(4) Efek peningkatan muatan inti Boron lebih kecil dari pada gaya tolak di antara elektron-elektron pada orbital 2p tersebut.

(5)

Keyakinan:

a Yakin

b Tidak Yakin

This phenomenon is similar to the phenomenon 6. It is noted that beryllium and boron in period 2, meanwhile magnesium and aluminum in period 3. However, both of the phenomena represent the comparison of the first ionization energy between Group 2 and Group 13. The correct answer in this context is "the first ionization energy of beryllium is greater than that of boron" due to "the 2p electron of boron has a lower penetrating power than the 2s electrons therefore it outweighing the increase in nuclear charge". Students performed scientific conception about 22%. In addition, some students have different conceptions, such as: "the 2s electron of beryllium has a lower penetrating power than the 1s electrons therefore it outweighing the increase in nuclear charge".

The misconceptions probed by the IEDI*M among High School Students

Table 5 lists the misconceptions probed by the IEDI. By addressing to Gurel *et al* (2015) and Kirbulut and Geban (2014), the following information is the rubric was used to indicate the misconceptions probed by high school students:

"(a) Misconception of one-tier was created according to participants' answers to the first tier of items. When a participant's answer to the first tier was the misconceptions, it was coded as 1; otherwise, 0.
(b) Misconception of two-tier was based on participant's answers to the first two-tier of items for each misconception. When a participant's answer to both the first and second tiers were the misconceptions, it was coded as 1; otherwise, 0.
(c) Misconception of three-tier was produced by considering the participant's answers to all tiers of items for each misconception. When a participant's answer to the first two tiers was the misconceptions and when she/he selects 'sure' in the third tier, it was coded as 1; otherwise, 0".

Table 6 presents the percentages of misconceptions for all tiers scores in this study. Accordingly, three-tier tests predict more accurately compared to two-tier and conventional multiple-choice tests about participants' misconceptions since three-tier tests include two-tier and confidence tier scores. The percentages of misconceptions decrease significantly from one-tier to three-tier scores. This result corroborated the studies conducted by Peşman and Eryılmaz (2010) and Kirbulut and Geban (2014). Table 6 also shows the most misconception has experienced by students, except item 2. The following box summarizes significant common misconceptions are identified (see Figure 1).

CONCLUSIONS AND IMPLICATIONS

This study explores high school students' understanding and confidence in answering questions about ionization energy. The findings indicated the part of misconceptions about ionization energy, especially for Group 1, 2, period 2, and period 3. For instance, many participants have problem about ionization energy of beryllium versus boron and magnesium versus aluminum as well as silicon versus phosphorus and phosphorus versus sulphur. It was noted that beryllium and boron in period 2, meanwhile magnesium and aluminum in period 3. This study revealed that, in general, a significant number of students did not adequately understand the trend of ionization energy across period 2 and period 3 and the factors influencing it.

Then, if we compare between three-tier test and two-tier test of ionization energy, the percentages of misconceptions decrease from two-tier to three-tier scores as well as from one-tier to two-tier. This result supported the advantage of using three-tier tests rather than conventional multiple-choice tests. Kirbulut & Geban (2014) documented that "three-tier tests provide more accurate results for students' misconceptions by differentiating misconceptions from lack of knowledge. In other words, through the conventional or two-tier tests, misconceptions are overestimated since false responses due to lack of knowledge are evaluated as misconceptions". Thus, by using three-tier test is effective in minimizing misconceptions of ionization energy if compare to two-tier test and one-tier test.

Based on these findings, there are some implications. First, chemistry teachers should be aware that when students are successful on conventional multiple choice tests it does not necessarily reflect their conceptual understanding of chemistry. Therefore, teachers should consider using assessment tools that provide opportunities to probe students' reasoning and perform confidently. Rationally, increasing students' interest in chemistry would be also triggered by assessment (Peteva, Makedonski, & Stancheva, 2014). Three tier diagnostic assessments become alternative solutions. Second, the Indonesian government should aware about the chemistry textbook since the most misconception either from textbooks or the pathways from teacher candidate → novice teacher → senior teacher → student. Third, this effort is one of the educational reforms in Indonesia, especially in assessment of science education (Suprapto, 2016).

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Table 1. The main stages in the development of the instrument

Previous Study (Tan *et al.*, 2005; Taber & Tan, 2007; Tan & Taber, 2011)		This study	
Two-tier		**Three-tier**	
First-tier	*MC (3 options): item 1-3; item 5-10* *MC (4 options): item 4*	First-tier	*MC (2 options): item 1-12*
Second-tier	*MC (3 options): item 1 and item 2* *MC (4 options): item 3, 4, 8, and 10* *MC (5 options): item 5, 6, 7, and 9*	Second-tier	*MC (3 options): item 1 and 2* *MC (4 options): item 3 – 12*
-		Third-tier	*Level of confidence (sure or unsure): all items*

Table 2. Participants' demographic data

Demographics		% Senior High School Students (n=118)
Gender	Male	69.49
	Female	30.51
Grade	10	33.90
	11	31.36
	12	34.74

Table 3. Six Levels of Conception (Gurel, Eryılmaz, & McDermott, 2015)

Phenomena (P) First-tier	Reasoning (R) Second-tier	Confidence Third-tier	Category
True	True	Sure	Scientific conception (SC)
True	False	Sure	False Positive (FP)
False	True	Sure	False Negative (FN)
False	False	Sure	Misconception (MSC)
True	True	Unsure	Lack of Knowledge– Guessing (LKg)
True	False	Unsure	
False	True	Unsure	
False	False	Unsure	Lack of Knowledge– Deficiency (LKd)

Table 4. The percentages of conception of ionization energy among HSSs

Conception level	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6
	Number of students (percentages)					
SC	***48(40.68)***	***72(61.02)***	***69(58.47)***	***31(26.27)***	***50(42.37)***	4(3.39)
FP	21(17.80)	***28(23.73)***	11(9.32)	***49(41.52)***	***28(23.73)***	22(18.64)
FN	9(7.63)	6(5.08)	4(3.39)	2(1.69)	8(6.78)	***41(34.74)***
MSC	***35(29.66)***	4(3.39)	***28(23.73)***	22(18.64)	19(16.10)	***32(27.12)***
LKg	4(3.39)	7(5.3)	4(3.39)	9(7.63)	10(8.47)	14(11.86)
LKd	1(0.85)	1(0.85)	2(1.69)	5(4.24)	3(2.54)	5(4.24)
Conception level	**Item 7**	**Item 8**	**Item 9**	**Item 10**	**Item 11**	**Item 12**
	Number of students (percentages)					
SC	***25(21.19)***	***29(24.58)***	14(11.86)	***33(27.97)***	10(8.47)	***26(22.03)***
FP	***49(41.52)***	***34(28.81)***	***27(22.88)***	***24(20.34)***	***54(45.76)***	20(16.95)
FN	0	2(1.69)	2(1.69)	5(4.24)	6(5.08)	5(4.24)
MSC	***35(29.66)***	***32(27.12)***	***52(44.07)***	***30(25.42)***	***32(27.12)***	***45(38.47)***
LKg	5(4.24)	15(12.71)	10(8.47)	20(16.95)	11(9.32)	12(10.17)
LKd	4(3.29)	6(5.08)	13(11.02)	6(5.08)	5(4.24)	10(8.47)

Note:

1. SC: Scientific Conception; FP: False Positive; FN: False Negative; MSC: Misconception; LKg= Lack of Knowledge-Guessing; LKd= Lack of Knowledge-Deficiency
2. The ***bold- italics*** means the percentage of this response > 20%, (typical response)

Table 5. The misconceptions probed by the IEDI*M

No	Misconception	Item Choices
1	"Once the outermost electron is removed from the sodium atom forming the sodium ion, the sodium ion will not combine with an electron to reform the sodium atom".	1A1,1A2
2	"When an electron is removed from the sodium atom, the attraction of the nucleus for the 'lost' electron will not be redistributed among the remaining electrons in the sodium ion".	2B2, 2B3
3	"The sodium atom is a less stable system than the sodium ion and a free electron".	3B2, 3B3, 3B4
4	"After the sodium atom is ionized, less energy is required to remove a second electron from the sodium ion (i.e. the second ionization energy is greater than the first ionization energy)".	4B1, 4B2, 4B3
5	"The first ionization energy of sodium is greater than that of magnesium".	5A1, 5A2, 5A4
6	"The first ionization energy of magnesium is less than that of aluminum".	6B1, 6B2, 6B4
7	"The first ionization energy of sodium is greater than that of aluminum".	7A1, 7A2, 7A3
8	"The first ionization energy of silicon is greater than that of phosphorus".	8A1, 8A2, 8A3
9	"The first ionization energy of phosphorus is less than that of sulphur".	9B1, 9B2, 9B3
10	"The first ionization energy of silicon is greater than that of sulphur".	10A1, 10A2, 10A4
11	"The first ionization energy of lithium is less than that of sodium".	11B1, 11B2, 11B3
12	"The first ionization energy of beryllium is less than that of boron".	12B2, 12B3, 12B4

Some misconceptions	vs	*Scientific conceptions*
Na < Mg < Al	vs	Na < Mg, Mg > Al, and Na < Al
Be < B	vs	Be > B
Si < P < S	vs	Si < P, P > S, and Si < S

Figure 1*.* The summarize of significant common misconceptions designed by high school students

Table 6*.* The percentages of misconceptions for one-tier, two-tier, and three-tier scores

Misconceptions	Percentages of Misconceptions		
	one-tier	two-tier	three-tier
Misconception 1 **)	39.83*	30.51*	29.66*
Misconception 2	11.02	4.24	3.39
Misconception 3 **)	28.82*	25.42*	23.73*
Misconception 4	24.58*	22.88*	18.64
Misconception 5	26.27*	18.64	16.10
Misconception 6 **)	71.19*	31.36*	27.12*
Misconception 7 **)	33.05*	33.05*	29.66*
Misconception 8 **)	35.59*	32.20*	27.12*
Misconception 9 **)	56.78*	55.08*	44.07*
Misconception 10 **)	35.59*	30.51*	25.42*
Misconception 11 **)	38.98*	31.36*	27.12*
Misconception 12 **)	50.85*	46.61*	38.14*

Note * = the percentages of misconceptions > 20%

** = All tiers (one-tier, two-tier, and three-tier) have misconceptions