Jurnal Pendidikan Kimia Indonesia
Volume 6, Issue 1, 2022, pp. 55-62
p-ISSN: 2087-9040 e-ISSN: 2613-9537
Open Access: https://doi.org/10.23887/jpk.v6i1

Formal Thinking Capabilities and Their Impact on Misconceptions of Electronic Configuration Materials

Maulidia Rezki [1*], Sri Winarni[2], Zarlaida Fitri[3]

[1,2,3] Program Studi Pendidikan Kimia Fakultas Keguruan dan Ilmu Pendidikan Universitas Syiah Kuala, Indonesia

ARTICLE INFO

Article history:
Received November 17, 2021
Revised November 25, 2021
Accepted March 20, 2022
Available online April 25, 2022

Kata Kunci:
Konfigurasi Elektron, Kemampuan Berpikir Formal, Miskonsepsi

Keywords:
Electron Configuration, Formal Thinking Ability, Misconception

ABSTRAK

Tidak semua siswa usia di atas 11 tahun telah mencapai kemampuan berpikir formal. Hal ini berdampak pada siswa sering mengalami miskonsepsi. Penelitian ini bertujuan untuk mengidentifikasi Kemampuan Berpikir Formal (KBF), miskonsepsi materi konfigurasi elektron yang dialami siswa, dan korelasi antara KBF dan miskonsepsi. Jenis penelitian ini adalah deskriptif kuantitatif. Sampel penelitian ini adalah siswa kelas X IPA di SMA Negeri 4 Takengon sebanyak 87 siswa.Pengumpulan data penelitian menggunakan soal tes Test of Logical Thinking (TOLT) dan tes diagnostik two-tier multiple choices¬ materi konfigurasi elektron. Hasil analisis TOLT menunjukkan sebanyak 31,0% siswa telah mencapai kemampuan berpikir formal dengan kriteria 'formal rendah". Hasil analisis tes diagnostik yang terdiri dari 20 indikator soal menunjukkan sebesar 34,9% siswa mengalami miskonsepsi materi konfigurasi elektron dengan kriteria "rendah". Miskonsepsi paling tinggi dialami siswa pada indikator "menentukan pola konfigurasi elektron berdasarkan aturan setengah penuh" yaitu sebanyak 47,1% dari 87 siswa. Hasil koefisien korelasi r = -0,818 menunjukkan adanya hubungan negatif yang signifikansi antara KBF dan miskonsepsi dengan interpretasi "tinggi" dan bersifat berlawanan. Hendaknya dalam proses pembelajaran kimia, dihadirkan strategi pembelajaran yang memperhatikan kemampuan berpikir formal. Pembelajaran yang dapat meningkatkan kemampuan berpikir formal siswa berpotensi mencegah miskonsepsi.

ABSTRACT

Not all students over the age of 11 have achieved formal thinking skills. It has an impact on students who often experience misconceptions. This study aims to identify Formal Thinking Ability (KBF), misconceptions about electron configuration material experienced by students, and the correlation between KBF and misconceptions. This type of research is descriptive and quantitative. The sample of this research was 87 students of class X Science at SMA Negeri 4 Takengon. The research data were collected using the Test of Logical Thinking (TOLT) test questions and two-tier multiple choices¬ diagnostic tests on electron configuration material. The results of the TOLT analysis showed that as many as 31.0% of students had achieved formal thinking skills with the criteria of 'low formal.' The results of the diagnostic test analysis consisting of 20 question indicators showed that 34.9% of students had misconceptions about electron configuration material with the "low" criteria. The highest misconception experienced by students on the indicator "determining the pattern of electron configurations based on the half-full rule" is 47.1% of 87 students. The correlation coefficient r = -0.818 indicates a significant negative relationship between KBF and misconceptions with a "high" and opposite interpretation. A learning strategy should pay attention to traditional thinking skills in the chemistry learning process. Learning that can improve students' traditional thinking skills has the potential to prevent misconceptions.

1. INTRODUCTION

Electron configuration material is one of the chemistry materials taught to tenth-grade senior high school students. The electron configuration material consists of several concepts, namely quantum numbers, orbital forms, rules in electron configuration, and the relationship between the periodic system of elements and electron configurations. Concepts in electron configuration generally fall into the abstract

Corresponding author.
*E-mail address: maulirezki24@gmail.com (Maulidia Rezki)

category (Juniarni et al., 2019; Mandasari et al., 2021; Ramdhani, 2015). There are several types of thinking, including systematic, logical, critical, and formal (Hassan et al., 2016; Nugroho et al., 2018; Pacheco & Herrera, 2021; Sidiq et al., 2021). Formal thinking skills are needed to understand abstract concepts based on Piaget's Theory of Intellectual Development (Gurcay & Gulbas, 2018; Hsu et al., 2022; Li & Sun, 2022). Thinking is an activity that uses the mind to generate ideas and ideas using existing information. Thinking can be done by connecting information with the problem at hand. Formal thinking allows individuals to reason from relationships between concepts (propositions) and understand complex systems of actual change without concrete or empirical evidence (Hidayat & Harahap, 2015; Nasution, 2015). Formal thinking skills consist of proportion thinking, correlation thinking, control variables, thinking probability, and combinations. Based on Piaget's theory, individuals at the age of 12 years achieve the ability to think formally. That is, tenth-grade high school students studying chemistry should have reached this level of formal thinking ability. Students are expected to be able to connect the concepts to be studied with concepts that have been understood previously (Juliansyah et al., 2016). Science problems require students to have the ability to solve, analyze, integrate, and evaluate abstract problems. These skills are formal thinking skills. Formal Thinking ability is very important so that students can understand basic concepts (Shobikhah et al., 2021; Vasilyeva & Lombrozo, 2020).

Not all students over the age of 11 have achieved formal thinking skills (Bird, 2010; Mari & Gumel, 2015; Valanides, 1999). It shows that not all students studying chemistry have developed formal thinking skills. The results showed that only 19.4% of tenth-grade students at SMA Negeri 9 Pontianak had reached the stage of formal thinking skills (Juliansyah et al., 2016). Formal thinking skills are related to student learning outcomes. The higher the formal thinking ability of students, the higher their learning outcomes (Mustofa et al., 2013). Not achieving formal thinking skills can cause students to have difficulty understanding chemical concepts (Oloyede, 2012). This difficulty can cause students to misunderstand chemical concepts. Misconceptions of chemistry that occur consistently are characteristic of misconceptions (Amaliyah & Nasrudin, 2019; Putri & Muhtadi, 2018; Sofiana & Wibowo, 2019). The misconception is someone's understanding that is different from the scientific community's understanding (Fajarianingtyas & Yuniastri, 2015; Mursadam et al., 2017; W. Yunitasari et al., 2013). Misconceptions must be overcome because chemical concepts are interrelated with each other. Misconceptions in prerequisite concepts can lead to misconceptions in the next concept (Apriadi & Redhana, 2019; Biswajit, 2019; Jusniar et al., 2020; Winarni & Syahrial, 2016). On the other hand, understanding prior knowledge significantly affects understanding the next related concepts (Mursalin, 2014; Salim & Hidayati, 2020; I. Yunitasari et al., 2019). Therefore, teachers need to prepare a good understanding of the basic concepts of chemistry in high school as initial knowledge during further studies (Maysara & Habiddin, 2019).

Several students have experienced the misconception of electron configuration material. Misconceptions about electron configuration, filling electrons with inappropriate orbitals based on elemental magnetism, and configuration experienced by students were 60.0; 48.6; and 60.0% (Necor, 2019). As many as 53.5% of students have misconceptions about electron configuration (Mursadam et al., 2017). One of the misconceptions is that in filling electrons according to the Aufbau rule, students experience a misconception of 20.0% by answering electron filling in orbitals starting from the highest subshell to full and then filling the lowest subshell (Tamungku et al., 2019). Suppose this misconception in the material of electron configuration is not resolved. In that case, the material on the periodic system of elements and chemical bonds has the potential to lead to misconceptions. Electron configuration is a prerequisite concept for matter in the periodic system of elements and chemical bonds. One of the initial ways to overcome misconceptions is to identify the causes of these misconceptions. The causes of misconceptions include: One of the causes of misconceptions is that students have not achieved formal thinking skills. The findings of previous research also state that formal thinking skills are needed by students so that students can understand concepts well (Juliansyah et al., 2016; Mustofa et al., 2013). Other research also states that formal thinking skills are very important for students to follow learning well (Hidayat & Harahap, 2015; Nasution, 2015). Several research results on the misconceptions of electron configuration material that have been mentioned above have not linked them to students' formal thinking skills. Therefore, the first step to overcoming chemical misconceptions is identifying students' formal thinking skills and their impact on misconceptions, especially electron configuration material. This study aims to analyze the impact of formal thinking skills on the misconceptions experienced by students in the electron configuration material.

2. METHODS

The type of research conducted is descriptive quantitative research. This research was carried out at SMA Negeri 4 Takengon in the odd semester of the 2020/2021 academic year. The research sample was taken using a purposive sampling technique: the tenth-grade science students, consisting of 3 classes with

87. All tenth graders had studied electron configuration material. The Test of Logical Thinking (TOLT) instrument was translated into Indonesian by Winarni in 2016 and used to measure students' formal thinking skills (Tobin, K.G & Capie, 1981; Winarni, 2019). The TOLT consists of 10 two-part multiple-choice questions. The first part contains questions with five answer choices, while the second part contains five reasons for the answers to the first part. In one item, students will get a score of 1 if they answer and give reasons correctly and a score of 0 for wrong answers (Etzler & Madden, 2014). TOLT has been tested with a reliability score of 0.61, and an r table score with a significance level of 5% is 0.159 (Winarni, 2019). The two-tier multiple choices diagnostic test instrument was used to identify misconceptions about the electron configuration material experienced by students. This diagnostic test consists of 20 multiple choice questions with two levels. Two experts carried out the validity assessment. The assessment results of the two validators obtained a validity percentage of 100%. The two-tier multiple-choice diagnostic test instrument was tested on 40 twelfth-grade science students at SMA Negeri 4 Takengon. Based on the experimental data and measured using the Spearman-Brown formula, the reliability value of the two-tier multiple choices diagnostic test for electron configuration materials is 0.88. Based on the test results, the reliability value includes the interpretation of "very high." The scores obtained will be analyzed and grouped based on the criteria for Formal Thinking Ability. Thus, the number of students who have achieved Formal Thinking Ability can be obtained.

In addition, the results of students' answers using two-tier multiple choices diagnostic test on the electron configuration material as many as 20 items. The student answers will be analyzed based on the diagnostic test assessment category. Thus, the number of students who experience misconceptions about the electron configuration material is obtained. After getting the results of the level of Formal Thinking Ability that students have and the misconceptions experienced by students, the correlation can be searched to determine the relationship between the independent variable of Formal Thinking Ability and the dependent variable (misconceptions), the Pearson Product Moment correlation statistic can be used. The Pearson Product Moment Correlation can be used to find a significant relationship between one variable and another. This hypothesis test is needed to describe the effect of the level of Formal Thinking Ability on the misconceptions experienced by students. The provisional assumption of this research is that there is a negative influence between these two variables. The two variables are opposite because the higher the level of students' Formal Thinking Ability, the lower the level of the misconception they experience.

3. RESULTS AND DICCUSSION

Results

The level of thinking ability that tenth grade Takengon high school students have achieved is 32.2% (concrete), 36.8% (concrete-formal transition), and 31% (low formal). The results showed three levels of thinking ability achieved by tenth-grade science students: concrete, concrete-formal transition, and low formal. Students who achieve Formal Thinking Skills are less than 50.0%. It means that students generally have not achieved Formal Thinking Ability when studying chemistry, especially the electron configuration material. The results are in line with the findings, which state that not all students who reach the age of 12 years and over are at the level of Formal Thinking Skills. (Bird, 2010; Mari & Gumel, 2015; Valanides, 1999). Many students who have not achieved Formal Thinking Ability when studying electron configuration material can potentially experience learning difficulties. The difficulty of learning to understand the material of electron configuration has the potential to lead them to understand the wrong concept. Consistently understanding the wrong concept based on the answers on the diagnostic test instrument is a characteristic of the occurrence of misconceptions. The identification results from the answers to the two-tier multiple choices diagnostic test show the different levels of students' understanding of the electron configuration material based on the average percentage of students' answers, as shown in Figure 1.

Figure 1. shows several students who stated that they understood the concept, did not understand it and experienced misconceptions in the electron configuration material. The average student who understands the concept is less than 50%, based on the study results. The achievement of understanding concepts below 65% is declared not to have fulfilled classical learning completeness (Wijayanto & Winarto, 2021). Several students have misconceptions and do not understand the concept of electron configuration material. The misconceptions experienced by students based on the answers to each item are presented in Table 1.

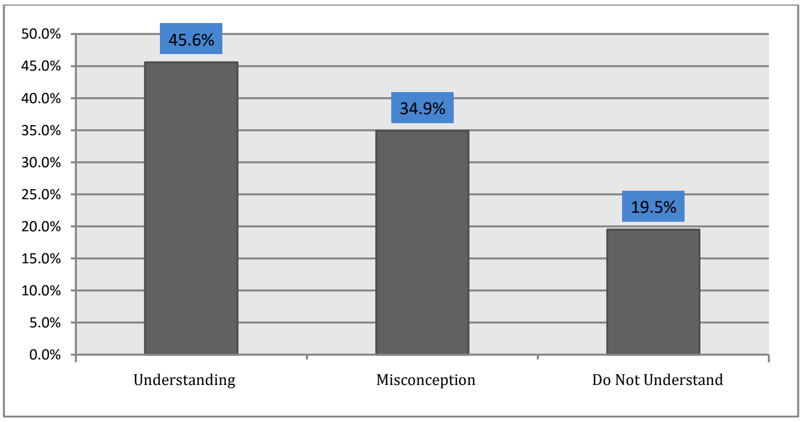

Figure 1. Percentage of students' understanding and misconceptions on electron configuration material

Table 1. Misconceptions experienced by students based on the answers to each item

Questions	Question Indicator	Misconception	
		Total students	(%)
1	Determine the four quantum numbers based on the outermost electron configuration	17	19,5
2	Determine four quantum numbers based on known atomic numbers	32	36,8
3	Determine the electron configuration based on four quantum numbers	31	35,6
4	Determine the pattern of electron configuration based on energy levels according to the Aufbau rule	38	43,7
5	Determine the atomic number and electron configuration by abbreviating the atomic number of the noble gases	33	37,9
6	Determine the same electron configuration as other elements in the form of ions	28	32,2
7	Determine the valence electrons from the electron configuration	35	40,2
8	Determine the pattern of electron configuration according to the Pauli prohibition	32	36,8
9	Determine unpaired electrons in orbitals according to Hund's rule	29	33,3
10	Determining an element based on the orbital diagram	29	33,3
11	Determine the filling of orbitals according to Hund's rule	30	34,5
12	Determine the electron configuration pattern according to the half-full rule	41	47,1
13	Determine the electron configuration pattern according to the full rules	34	39,1
14	Determine the atomic number and location of elements (groups and periods) in the periodic table of elements based on their electron configurations	32	36,8
15	Determine the location of the elements (groups and periods) in the periodic system of elements based on the four quantum numbers	26	29,9
16	Determine the electron configuration by knowing the groups in the periodic system of elements	32	36,8
17	Determine the shape of the orbital based on the subshell	29	33,3
18	Determine the outer electron configuration of a charged element	35	40,2
19	Determine the charge of an element based on its electron configuration	17	19,5
20	Determine the group elements in the periodic table of elements	27	31,0
	Average	30,3	34,9

The lowest misconceptions were experienced by students in items number 1 and 19. As many as 19.5% of students were identified on the indicators "determining four quantum numbers based on the outermost electron configuration" and "determining the charge of the element based on the electron configuration." Students in item number 12 experienced the highest misconception. A total of 47.1% of students were identified. The identification of misconceptions about electron configuration material experienced by students is presented in Table 2.

Table 2. Misconceptions experienced by students in determining the value of quantum numbers

Misconception	Question Number	Student Answer	Total students (%)
The azimuth quantum number (l) for the s subshell is 2 and has 1 orbital which is 0 so that the value of the magnetic quantum number (m) = 0	1	B/4	9,2
The azimuth quantum number (l) for the s subshell is 2 and has 1 orbital which is 0 so the value of the magnetic quantum number (m) = +1	1	A/4	1,1
The azimuth quantum number (l) for the s subshell is 3 and has 3 orbitals, namely -1,0,1 so the value of the magnetic quantum number (m) = -2	1	C/5	1,1
The azimuth quantum number (l) for the s subshell is 1 and has 5 orbitals, namely -2, -1,0,1,2 so the value of the magnetic quantum number (m) = -2	1	C/1	3,4
The azimuth quantum number (l) for the s subshell is 2 and has 1 orbital which is 0 so that the value of the magnetic quantum number (m) = -1	1	D/4	4,6

Based on Table 2, students' assumptions in answering questions include misconceptions. The four quantum numbers of 2s are n = 2, l = 0, m = 0, s = +1/2 or -1/2. The azimuth quantum number score (l) determines the subshell, while the magnetic quantum number (m) determines the orbital orientation. Therefore, the correct concept is that the azimuth quantum number (l) for the s subshell is 0 and has 1 orbital, namely 0 so that the value of the magnetic quantum number (m) = 0. If in the ionic state, element P has the same electron configuration as the electron configuration. Ar. Based on the Aufbau principle, the electron configuration of Ar is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$ and the electron configuration of P is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$. Based on the electron configuration, element P requires 3 electrons so that the configuration of the two elements is the same. The electron configuration for the elements Cr and Cu must pay attention to atomic stability. The electron configuration of Cr follows the Aufbau principle without considering the stability aspect of the atom, including the category of misconceptions. The element is more stable when the 3d subshell is fully or partially filled. The stability of the d subshell can be seen in terms of magnetic properties. The element Cr is ferromagnetic because there are more unpaired electrons in the orbitals. So the proper electron configuration of Cr is to follow the half-complete rule.

All students' answers from the Formal Thinking Ability test questions as variable X and all students' answers who experience misconceptions as variable Y. Variable X and variable Y are first tested for normality to find out that the two variables are normally distributed. The normality test for both variables used the Kolmogorov-Smirnov test with SPSS 21 versions 2016. Based on the normality test results for the X and Y variables, a significance score of 0.325 > 0.05 was obtained. Then the residual values of the two variables have been normally distributed. Thus, a correlation test can be performed using the Pearson Product Moment formula with SPSS 21 versions 2016. The calculation results of the correlation score obtained are r = – 0.818. Based on the interpretation of the Pearson Product Moment correlation coefficient, the correlation between Formal Thinking Ability and misconceptions is "high." If r = -1, the relationship between the two variables is linear, negative, and very high. A negative r score indicates the opposite correlation of the X variable and Y variable. The higher the score of Formal Thinking Ability (variable X) obtained by students, the lower the misconceptions (variable Y) experienced by students. Based on the determination test, the r-square score was 0.670. It means a significant influence/contribution on the not yet achieved Formal Thinking Ability to misconceptions of 67.0%. Other factors influence the rest by 33%. Hypothesis testing using a t-test got a tcount score of -13.126. The ttable score at the 0.05 level of significance is 1.6629. Therefore, it can be concluded that the score tcount > ttable, which means Ha is accepted and H0 is rejected. It proves that students' level of Formal Thinking Ability hurts the misconceptions experienced by students.

Discussion

Misconceptions occur allegedly due to a lack of detailed explanation of this concept so that students do not understand. Understanding is the ability to think, know something, and see it from a different point of view (Fitrah, 2017; Jeheman et al., 2019; Nasrum, 2020). Dynamic understanding encourages students to think creatively to solve their problems (Dwi et al., 2013; Fitri & Afnita, 2020; Yulianty, 2019). Students who can understand the concept of learning material will be able to answer questions correctly. If students' understanding is lacking, there will be misconceptions. Students who are still wrong in answering questions can also have misconceptions (Fajarianingtyas & Yuniastri, 2015; Mursalin, 2014). Misconceptions are students' thoughts that are wrong or contrary to scientific theories. The misconception is a problem in thinking knowledge and understanding concepts that will lead to the low ability of students and not achieving complete learning (Yunitasari et al., 2019). Misconceptions can come from the teacher's limited explanation, low attention, shallow notes, misunderstood reading books, and the many limitations of textbook explanations (Devetak et al., 2010; Pasaribu & Saparini, 2017). The misconception is a wrong understanding and has been in someone's understanding for a long time. Teachers are required to remediate misunderstandings experienced by students. The teacher's difficulty dispelling student misunderstandings is a large number of students in the school and the short study time (Laksana, 2016; Sholihat et al., 2017). If the concept that students received from the beginning is wrong, the teacher can cope with a new concept that is still relevant. Other factors that can influence misconceptions include students not understanding the teacher's explanations, teachers not explaining in detail, lack of representation for abstract concepts, and inadequate explanations in the textbooks used. Sources of misconceptions include discrepancies in presenting analogies, ontologically varied concept categorization, presentation of concepts in textbooks, and teacher training. Students who have higher thinking skills will reduce the misconceptions experienced by students. It is in line with previous research, which states that the higher the students' formal thinking ability, the fewer misconceptions they experience (Juliansyah et al., 2016; Mustofa et al., 2013; Nasution, 2015). Thus, learning that can improve students' thinking skills aligns with efforts to prevent misconceptions.

4. CONCLUSION

Most students have not developed formal thinking skills. The student's misconception of electron configuration material is the highest on the indicator "determining the electron configuration pattern based on the half-full rule." There is a significant relationship with high interpretation between students' formal thinking skills and misconceptions of the opposite nature. The higher the achievement of Formal Thinking Ability, the fewer misconceptions experienced by students. It should be in the process of learning chemistry, applying efforts that can help students achieve Formal Thinking Skills. Learning that can improve students' thinking skills can at the same time prevent misconceptions.

5. REFERENCES

Amaliyah, M., & Nasrudin, H. (2019). Melatihkan Keterampilan Berpikir Kritis Peserta Didik Melalui Strategi Predict Observe Explain (POE) Pada Materi Kesetimbangan Kimia Kelas XI SMAN 11 Surabaya. *Unesa Journal of Chemical Education*, *8*(3), 2252–9454. https://doi.org/10.1017/CBO9781107415324.004.

Apriadi, N. N. S., & Redhana, I. W. (2019). Identifikasi Miskonsepsi Siswa Kelas X Pada Topik Reaksi Redoks. *Jurnal Pendidikan Kimia Indonesia*, *2*(2), 70. https://doi.org/10.23887/jpk.v2i2.16617.

Bird, L. (2010). Performance in General Chemistry. *Journal of Chemical Education*, *87*(5), 541–546. https://doi.org/https://doi.org/10.1021/ed8001754.

Biswajit, B. (2019). Misconceptions in Shape of Molecule: Evidence from 9th Grade Science Students. *Educational Research and Reviews*, *14*(12), 410–418. https://doi.org/10.5897/err2019.3755.

Devetak, I., Vogrinc, J., & Glazar, S. A. (2010). States of Matter Explanations in Slovenian Textbooks for Students Aged 6 to 14. *International Journal of Environmental and Science Education*, *5*(2), 217–235.

Dwi, I. M., Arif, H., & Sentot, K. (2013). Pengaruh strategi problem based learning berbasis ICT terhadap pemahaman konsep dan kemampuan pemecahan masalah fisika. *Jurnal Pendidikan Fisika Indonesia*, *9*(1), 8–17. https://doi.org/10.15294/jpfi.v9i1.2575.

Etzler, F. M., & Madden, M. (2014). The Test of Logical Thinking As A Predictor of First-Year Pharmacy Students' Performance in Required First-Year Courses. *American Journal of Pharmaceutical Education*, *78*(6), 4–7. https://doi.org/10.5688/ajpe786121.

Fajarianingtyas, D. A., & Yuniastri, R. (2015). Upaya reduksi miskonsepsi siswa pada konsep reaksi redoks melalui model guided inquiry di SMA Negeri I Sumenep. *Jurnal Lentera Sains (Lensa)*, *5*(1). https://doi.org/10.24929/lensa.v5i2.248.

Fitrah, M. (2017). Pembelajaran Berbasis Masalah Untuk Meningkatkan Pemahaman Konsep Matematika Pada Materi Segiempat Siswa Smp. *KALAMATIKA Jurnal Pendidikan Matematika*, *2*(1), 51. https://doi.org/10.22236/kalamatika.vol2no1.2017pp51-70.

Fitri, M., & Afnita. (2020). Korelasi keterampilan membaca pemahaman dan keterampilan menulis teks eksposisi siswa kelas VII SMP Negeri 11 Padang. *Jurnal Penelitian Bidang Pendidikan*, *26*(2), 77–81. https://doi.org/10.24114/jpbp.v26i2.17925.

Gurcay, D., & Gulbas, E. (2018). Determination of Factors Related to Students' Understandings of Heat, Temperature and Internal Energy Concepts. *Journal of Education and Training Studies*, *6*(2), 65. https://doi.org/10.11114/jets.v6i2.2854.

Hassan, S. R., Rosli, R., & Zakaria, E. (2016). The Use of i-Think Map and Questioning to Promote Higher-Order Thinking Skills in Mathematics. *Creative Education*, *07*(07), 1069–1078. https://doi.org/10.4236/ce.2016.77111.

Hidayat, M. I., & Harahap, M. B. (2015). Efek Model Pembelajaran Inquiry Training Berbasis Multimedia Lectora Dan Kemampuan Berpikir Formal Terhadap Hasil Belajar Fisika Siswa (Vázquez & de Anglat, 2009). KBF terdiri atas (1) berpikir proporsi; (2) berpikir korelasi; (3) mengontrol variabel; (4). *Jurnal Pendidikan Fisika*, *4*(1). https://doi.org/10.22611/jpf.v4i1.2565.

Hsu, F.-H., Lin, I.-H., Yeh, H.-C., & Chen, N.-S. (2022). Effect of Socratic Reflection Prompts via video-based learning system on elementary school students' critical thinking skills. *Computers & Education*, *183*. https://doi.org/10.1016/j.compedu.2022.104497.

Jeheman, A. A., Gunur, B., & Jelatu, S. (2019). Pengaruh Pendekatan Matematika Realistik terhadap Pemahaman Konsep Matematika Siswa. *Mosharafa: Jurnal Pendidikan Matematika*, *8*(2), 191–202. https://doi.org/10.31980/mosharafa.v8i2.454.

Juliansyah, Kurniati, T., & Fitriani. (2016). Analisis Hubungan Kemampuan Berpikir Formal Dengan Hasil Belajar Siswa Dalam Pembelajaran Kimia Di Kelas X Sma Negeri 9 Pontianak. *Ar-Razi Jurnal Ilmiah*, *4*(2). https://doi.org/10.29406/arz.v4i2.678.

Juniarni, D. I., Fadhilah, R., & Kurniawan, R. A. (2019). Pengembangan Permainan Lego Kimia Sebagai Media Pembelajaran Sub Materi Konfigurasi Elektron Pada Siswa Kelas X SMA Muhammadiyah 1 Pontianak. *Ar-Razi Jurnal Ilmiah*, *7*(1), 47–55. https://doi.org/DOI: http://dx.doi.org/10.29406/ar-r.v7i1.1381.

Jusniar, J., Effendy, E., Budiasih, E., & Sutrisno, S. (2020). Misconceptions in Rate of Reaction and their Impact on Misconceptions in Chemical Equilibrium. *European Journal of Educational Research*, *9*(4), 1405–1423. https://doi.org/10.12973/eu-jer.9.4.1405.

Laksana, D. N. L. (2016). Miskonsepsi Dalam Materi IPA Sekolah Dasar. *Jurnal Pendidikan Indonesia |*, *5*(2), 166–175. https://doi.org/10.23887/jpi-undiksha.v5i2.8588.

Li, L., & Sun, Y. (2022). The rule of law in education and its relationship to thinking skills. *Thinking Skills and Creativity*, *44*. https://doi.org/10.1016/j.tsc.2022.101034.

Mandasari, Y. D., Subandowo, M., & Gunawan, W. (2021). Pengembangan Media Pembelajaran Interaktif Konfigurasi Elektron Elektronik Otomatis Mata Pelajaran IPA Di Masa Pandemi Covid-19. *Jurnal Kajian Teknologi Pendidikan*, *4*(3). https://doi.org/10.17977/um038v4i32021p309.

Mari, J. S., & Gumel, S. A. (2015). Effects of Jigsaw Model of Cooperative Learning on Self-Efficacy and Achievement in Chemistry among Concrete and Formal Reasoners in Colleges of Education in Nigeria. *International Journal of Information and Education Technology*, *5*(3), 196–199. https://doi.org/10.7763/ijiet.2015.v5.501.

Maysara, M., & Habiddin, H. (2019). The Implementation of Reciprocal Teaching Model to Improve Students' Achievement on Acid-Base Concepts. *J-PEK (Jurnal Pembelajaran Kimia)*, *4*(1), 14–17. https://doi.org/10.17977/um026v4i12019p014.

Mursadam, Wildan, & Ramdani, A. (2017). Jurnal penelitian pendidikan ipa. *Jurnal Penelitian Pendidikan IPA*, *4*(2), 17–25. https://doi.org/https://doi.org/10.29303/jppipa.v3i2.87.

Mursalin. (2014). Meminimalkan Miskonsepsi Pada Materi Rangkaian Listrik Dengan Pembelajaran Predict-Observe-Explain. *Jurnal Ilmu Pendidikan*, *20*(1). https://doi.org/10.17977/jip.v20i1.4383.

Mustofa, Pikoli, M., & Suleman, N. (2013). Hubungan Antara Kemampuan Berpikir Formal dan Kecerdasan Visual-Spasial dengan Kemampuan Menggambarkan Bentuk Molekul Siswa Kelas XI MAN Model Gorontalo Tahun Ajaran 2010 / 2011. *Jurnal Entropi*, *8*(1), 551–561.

Nasrum, A. (2020). Pengembangan Instrumen Evaluasi Pemahaman Konsep Kalkulus Berbasis Komputer. *HISTOGRAM: Jurnal Pendidikan Matematika*, *4*(1), 78. https://doi.org/10.31100/histogram.v4i1.540.

Nasution, S. M. (2015). Implementasi Model Pembelajaran Inquiry Training Dalam Pembelajaran Fisika Untuk Meningkatkan Kemampuan Berpikir Formal Siswa. *Jurnal Pendidikan Fisika Indonesia*, *11*(2). https://doi.org/10.15294/jpfi.v11i2.4679.

Necor, D. C. (2019). Conceptual Understanding of Students on Electron Configuration. *International Journal of Science and Research*, *8*(5), 336–342.

Nugroho, P. B., Nusantara, T., As'ari, A. R., Sisworo, Hidayanto, E., & Susiswo. (2018). Critical Thinking Disposition: Students Skeptic in Dealing with Ill-Logical Mathematics Problem. *International*

Journal of Instruction, *11*(3), 635–648. https://doi.org/10.12973/iji.2018.11343a.

Oloyede, O. I. (2012). The Relationship between Acquisition of Science Process Skills , Formal Reasoning Ability and Chemistry Achievement. *International Journal of Advanced and Applied Sciences*, *8*(1), 1–4.

Pacheco, C., & Herrera, C. (2021). A conceptual proposal and operational definitions of the cognitive processes of complex thinking. *Thinking Skills and Creativity*, *39*. https://doi.org/10.1016/j.tsc.2021.100794.

Pasaribu, A., & Saparini. (2017). Pengembangan Bahan Ajar Berbasis Kontekstual untuk Meremidiasi Miskonsepsi pada Materi Gaya dan Hukum Newton. *Jurnal Inovasi Dan Pembelajaran Fisika*, *4*(2), 36–47. https://doi.org/10.36706/jipf.v4i1.4264.

Putri, D. P. E., & Muhtadi, A. (2018). Pengembangan multimedia pembelajaran interaktif kimia berbasis android menggunakan prinsip mayer pada materi laju reaksi. *Jurnal Inovasi Teknologi Pendidikan*, *5*(1), 38–47. https://doi.org/10.21831/jitp.v5i1.13752.

Ramdhani, I. M. (2015). Pengembangan Media Flash Card Sistem Periodik Unsur Untuk Meningkatkan Retensi Daya Ingat Peserta Didik Disabilitas Pendengaran Di SMA. *Journal of Disability Studies*, *2*(2). https://doi.org/10.14421/ijds.2204.

Salim, & Hidayati, S. R. (2020). Penerapan Levels of Inquiry Meningkatkan Penguasaan Konsep Kimia Pada Siswa Dengan Pengetahuan Awal Berbeda. *Jurnal Pendidikan Kimia Indonesia*, *4*(2), 78–87.

Shobikhah, A., Siswono, T. Y. E., & Prastiti, T. D. (2021). Analisis Kemampuan Berpikir Kreatif Siswa Berbakat Dalam Menyelesaikan Soal Olimpiade Matematika. *JPMI (Jurnal Pendidikan Matematika Indonesia)*, *6*(2). https://doi.org/10.26737/jpmi.v6i2.2520.

Sholihat, F. N., Samsudin, A., & Nugraha, M. G. (2017). Identifikasi Miskonsepsi dan Penyebab Miskonsepsi Siswa Menggunakan Four-Tier Diagnostic Test Pada Sub-Materi Fluida Dinamik: Azas Kontinuitas. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*. https://doi.org/10.21009/1.03208.

Sidiq, Y., Ishartono, N., Desstya, A., Prayitno, H. J., Anif, S., & Hidayat, M. L. (2021). Improving Elementary School Students' Critical Thinking Skill in Science Through Hots-Based Science Questions: A Quasi-Experimental Study. *Jurnal Pendidikan IPA Indonesia*, *10*(3), 378–386. https://doi.org/10.15294/jpii.v10i3.30891.

Sofiana, S., & Wibowo, T. (2019). Pengembangan Modul Kimia Socio-Scientific Issues (SSI) Materi Reaksi Reduksi Oksidasi. *Journal of Educational Technology*, *1*(2). https://doi.org/10.21580/jec.2019.1.2.4382.

Tamungku, R., Tani, D., & Tuerah, J. (2019). Analisis Miskonsepsi Siswa dengan Menggunakan Tes Diagnostik Two-Tier Multiple Choice pada Materi Struktur Atom di SMA Negeri 1 Remboken. *Oxsigenius*, *1*(2), 66–71. https://doi.org/https://doi.org/10.37033/ojce.v1i2.109.

Tobin, K.G & Capie, W. (1981). The Development and Validation of A Group Test of Logical Thinking. *Educational and Psychological Measurement*, *41*, 413–423. https://doi.org/http://dx.doi.org/10.1177/001316448104100220.

Valanides, N. (1999). Formal Reasoning Performance of Higher Secondary School Students : *European Journal of Psychology of Education*, *XIV*(1), 109–127. https://doi.org/https://doi.org/10.1007/BF03173114.

Vasilyeva, N., & Lombrozo, T. (2020). Structural thinking about social categories: Evidence from formal explanations, generics, and generalization. *Cognition*, *204*. https://doi.org/10.1016/j.cognition.2020.104383.

Wijayanto, T., & Winarto, D. S. (2021). Peningkatan Hasil Belajar Siswa Melalui Model Kooperatif dengan Pendekatan Tipe Numbered Heads Together. *Saintifika*, *23*(1).

Winarni, S. (2019). *Concept Approval Strategy untuk Mencegah Miskonsepsi Materi Sifat Koligatif Larutan*. Program Pascasarjana Universitas Negeri Malang.

Winarni, S., & Syahrial, S. (2016). Miskonsepsi Kimia yang Disebabkan Pernyataan Nonproposisi. *JPS (Jurnal Pendidikan Sains)*, *4*(4), 122–129. https://doi.org/10.17977/jps.v4i4.8195.

Yulianty, N. (2019). Kemampuan Pemahaman Konsep Matematika Siswa Dengan Pendekatan Pembelajaran Matematika Realistik. *Jurnal Pendidikan Matematika Raflesia*, *4*(1), 60–65. https://doi.org/10.33449/jpmr.v4i1.7530.

Yunitasari, I., Widarti, H. R., & Nazriati, N. (2019). Miskonsepsi Asam Basa Berbasis Multipel Representasi pada Lintas Jenjang Pendidikan. *Jurnal Pendidikan Teori, Penelitian, Dan Pengembangan*, *4*(12). https://doi.org/10.17977/jptpp.v4i12.13082.

Yunitasari, W., Susilowati, E., & Nurhayati, N. (2013). Pembelajaran Direct Instruction Disertai Hierarki Konsep Untuk Mereduksi Miskonsepsi Siswa Pada Materi Larutan Penyangga Kelas XI IPA Semester Genap Sma Negeri 2 Sragen Tahun Ajaran 2012/2013. *Jurnal Pendidikan Kimia Universitas Sebelas Maret*, *2*(3), 182–190.