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A Systematic Literature Review: Findings of Misconceptions in Atomic Structure Chemistry

Yosephine Debbie Damayanti, Melania Eva Wulanningtyas*

Universitas Katolik Parahyangan

Keywords

misconceptions, atomic structure, chemistry, SLR

Abstract

This research aims to provide a comprehensive overview of the current state of research on atomic structure misconceptions, as well as identifying the best strategies to overcome them. Systematic Literature Review (SLR) approach to identify, study, evaluate, and interpret research results related to misconceptions in atomic structure material at the high school level. This approach was chosen because it is able to provide a systematic and comprehensive overview of various relevant research, so that it can find patterns, trends and research gaps that exist over a certain period of time. The analysis focuses on the forms of misconceptions, causal factors, and learning strategies to overcome these misconceptions which are based on the results of literacy studies, especially those originating from 10 selected articles (which were selected based on SLR-based research methods). The research results show that there are misconceptions in the concept of atomic structure starting from the concept of the atomic model, the quantum mechanical model, the Aufbau principle, the Hund principle, the Pauli exclusion principle, to the sub-atomic concept of the composition of an atom. The results of this study provide important insight for teachers and curriculum developers regarding steps that can be taken to reduce misconceptions.

*Correspondence Address:
E-mail:
melaniaeva@unpar.ac.id

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INTRODUCTION

Chemistry learning is a learning that emphasizes concepts and their continuous nature between one another (Jusriana *et al*., 2022). This is the reason why it is important for students to have a deep understanding of chemistry material or basic chemistry concepts to be able to understand advanced chemistry concepts (Hidayati *et al*., 2019). Misunderstanding of chemical concepts (misconceptions) that occur in students since class (Damayanti & Priatmoko, 2023). Misconceptions are one of the causes of learning difficulties for students. Misconceptions can come from books, teaching/knowledge obtained during classroom learning by teachers, students' personal thoughts after independent study, the internet, or other sources (Antari & Sumarni, 2020). Misconceptions can be defined as a conception or cognitive structure that is not in accordance with the results of research or experts and is embedded in students' minds (Hidayat *et al*., 2020). Misconception or misunderstanding of chemistry concepts will be an obstacle to the process of accepting and assimilating new knowledge in students (Kefi *et al*., 2021). This is what underlies the importance of identifying student misconceptions in basic chemistry material (basic concepts), one of which is the concept of atomic structure.

Atomic structure is one of the basic concepts in chemistry which is the basis for understanding various advanced materials (A'yun & Nuswowati, 2018). However, class X students often face difficulties understanding this concept in depth. Many studies show that misconceptions about atomic structure are a common phenomenon at various levels of education (Wardhani *et al*., 2016). These misconceptions include a wrong understanding of the atomic model, electron configuration, and the nature of subatomic particles such as protons, neutrons and electrons. For example, research by Nurhayati dkk. (2017) by title "Analisis Miskonsepsi Siswa SMA pada Konsep Struktur Atom Menggunakan Tes Diagnostik" revealed that more than 40% of students experienced misconceptions in describing electron orbits in the Bohr atomic model.

An inaccurate understanding of the concept of atomic structure can be rooted in the abstract nature of matter itself (Mawarni, 2017). This topic involves concepts that are difficult to access directly by the human senses, such as subatomic particles and the internal structure of atoms. Other research by Putri dan Rahman (2019) entitled "Evaluasi Miskonsepsi pada Materi Struktur Atom: Studi Kasus di SMA Kota Bandung", showed that students often incorrectly assume that electrons circle the atomic nucleus in perfectly circular paths. The results of this research also reveal that these conceptual errors are mostly caused by the use of conventional learning media which does not support visualization (Liu *et al., 2024)*. The urgency of a proper understanding of atomic structure cannot be ignored. As a fundamental topic, atomic structure is the basis for mastering other materials such as chemical bonds, periodic properties of elements, and chemical reactions (Alfa, 2023). Lack of understanding of this material can have implications for students' failure to understand more complex chemical concepts. This is in line with the results of research by Wibowo dkk. (2021), entitled "Hubungan Antara Miskonsepsi Struktur Atom dan Pemahaman Ikatan Kimia di SMA Negeri Surakarta", who found a strong correlation between misconceptions about atomic structure and difficulties in understanding the properties of ionic and covalent bonds.

Systematic studies to identify, assess, and evaluate misconceptions about atomic structure are needed (Oteng *et al*., 2023). Data obtained from this literature review can provide important insights into patterns of misconceptions, their causal factors, and effective methods for overcoming them. This research aims to conduct a systematic literature review of studies on atomic structure conducted between 2015 and 2025. This review will not only identify relevant research but also provide a critical evaluation of the approaches that have been applied to overcome misconceptions. As an illustration, research by Suharto *et al.* (2020), entitled "Pengembangan Media Pembelajaran Interaktif untuk Mengatasi Miskonsepsi pada Struktur Atom", shows that a technology-based approach can significantly reduce student misconceptions. This approach involves dynamic visualization of atomic structures and interactive simulations that help students understand abstract concepts better. Other research by Lestari dan Anggraeni (2022), "Efektivitas Model Pembelajaran Berbasis Masalah dalam Meningkatkan Pemahaman Konsep Struktur Atom", also supports the importance of using innovative methods in teaching.

Based on these several things, this research is designed to provide a comprehensive picture of the current state of research on atomic structure misconceptions, as well as identifying the best strategies to overcome them. It is hoped that this research can become an important reference for educators, researchers and curriculum developers in improving the quality of chemistry learning in Indonesia.

METHODS

This research uses a Systematic Literature Review (SLR) approach to identify, study, evaluate, and interpret research results related to misconceptions about atomic structure material at the high school level. This approach was chosen because it is able to provide a systematic and comprehensive overview of various relevant research, so that it can find patterns, trends and research gaps that exist within a certain period of time (Halimah & Dewi, 2024). The research process begins with the formulation of research questions aimed at guiding data collection and analysis (Arissona Dia Indah Sari *et al.*, 2023). Some of the main questions asked include: what are the most common forms of misconceptions in atomic structure material at the high school level, what factors cause the emergence of misconceptions in atomic structure material, what strategies have been developed to overcome these misconceptions, and what are the trends? research on misconceptions about atomic structure in the 2015-2025 period.

The next stage is a literature search carried out using Google Scholar as the main source. Key words used in the search included "atomic structure misconceptions", "misconceptions in atomic structure", "chemistry student misconceptions", "high school atomic structure misconceptions", and "atomic structure misconception interventions". To expand the scope, other keyword combinations such as “chemistry misconception diagnosis” and “chemistry learning media development” were also applied. The search focused on articles published between 2015 and 2025, with additional filters to ensure relevance and quality of the literature (Zulkarnain *et al.*, 2022). SLR is carried out based on three main principles, namely transparency, replication and objectivity. Transparency means that all stages of the research process, from literature search, selection, to analysis, are documented in detail so that they can be understood by readers or other researchers. The principle of replication allows other researchers to repeat the research process using the same procedures, so that the results can be tested again. Objectivity requires that the entire process be conducted without bias, with clear inclusion and exclusion criteria to ensure only relevant and quality articles are selected (Norlita *et al.*, 2023).

Literature selection was carried out in two stages, namely initial screening based on the title and abstract, and further selection through full text examination. Articles that pass the selection must meet the inclusion criteria, namely focusing on misconceptions about atomic structure at the high school level, published in journals indexed by Google Scholar, using diagnostic or intervention methods, and written in Indonesian or English. Articles that were irrelevant, did not specifically discuss atomic structure, or had no full text accessible were eliminated in the selection process. After selection, data from selected articles were extracted for analysis. The information collected includes research title, author, year of publication, research methods, main findings related to misconceptions, and proposed solutions or interventions. The data that has been collected is analyzed thematically using a descriptive and evaluative approach to identify research trends, evaluate the effectiveness of the methods that have been applied, and provide recommendations based on the study results. The results of this study are reported in the form of a structured narrative with flow diagrams and tables as support. The literature search and selection process was carried out carefully and well documented. All stages from search, selection, to data analysis were carried out systematically by a single researcher guided by SLR principles. These principles are applied to ensure that research results are not only academically relevant but can also be used as a valid and reliable reference in the development of chemistry learning (Halimah & Dewi, 2024). All the stages in more detail can be seen in Figure 1.

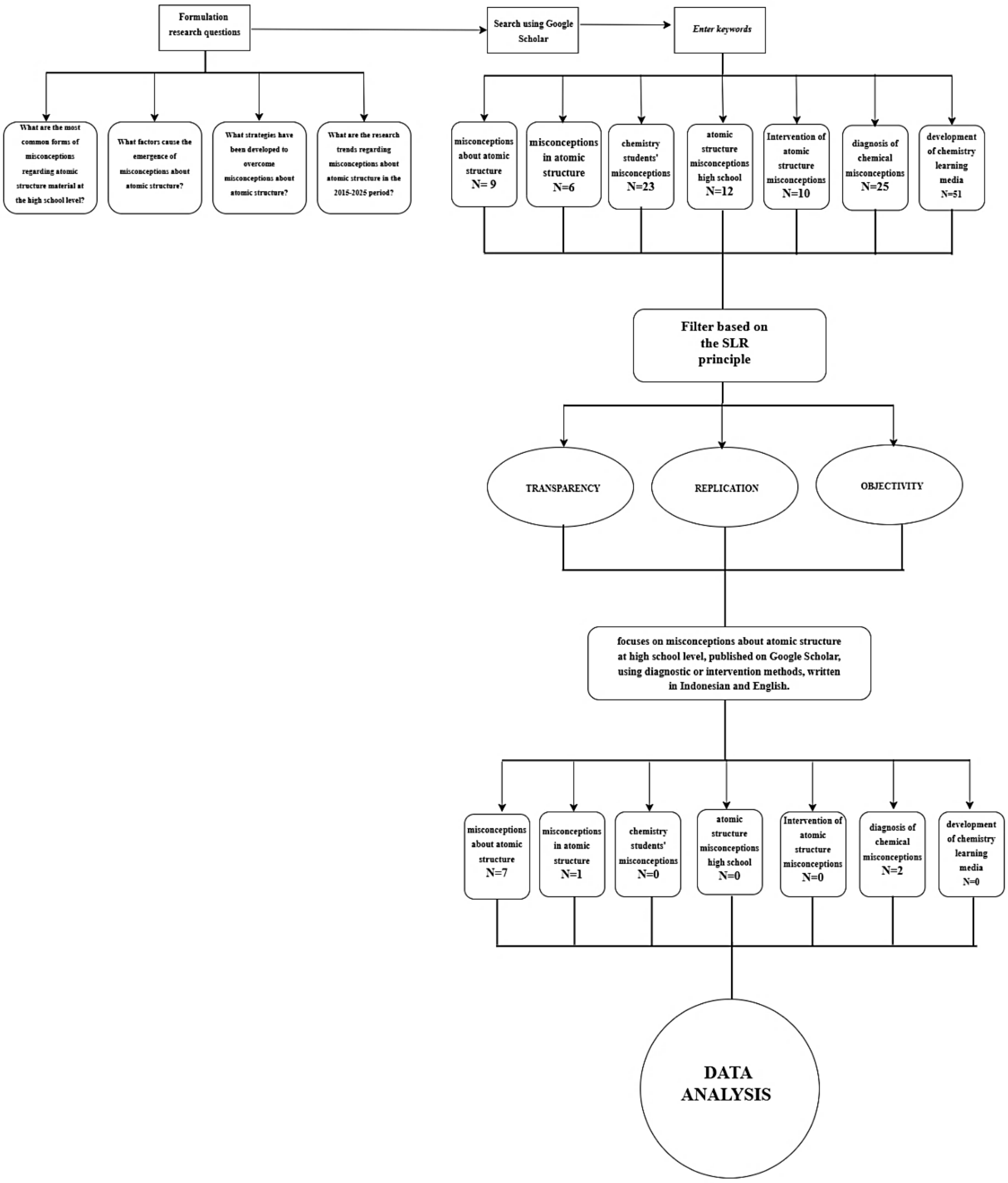

Figure 1. Stages of SLR-Based Research Methods

RESULTS AND DISCUSSION

The analysis focuses on the forms of misconceptions, causal factors, and learning strategies to overcome these misconceptions which are based on the results of literacy studies, especially those originating from 10 selected articles (which were selected based on SLR-based research methods). Research data was processed using a Systematic Literature Review (SLR) approach to obtain a comprehensive picture of misconception patterns and intervention steps that have been taken. Students' misconceptions in the concept of atomic structure are found in various fundamental aspects. Factors causing student misconceptions include various aspects, both from a pedagogical perspective and material characteristics. One of the main causes is the use of conventional learning media which does not support the visualization of abstract concepts. Textbooks and teacher presentations often focus only on symbolic or macroscopic representations without providing adequate submicroscopic descriptions. The lack of integration between the three levels of chemical representation, namely macroscopic, submicroscopic and symbolic, is also the main cause of students' understanding errors. Teachers who do not master concepts can also exacerbate students' misconceptions (Marlena *et al.*, 2022). Delivery of material that is not systematic and lacks depth often causes confusion among students. Another influencing factor is the abstractness of the concept of atomic structure itself. This topic involves subatomic particles and the principles of quantum mechanics which are difficult for students to understand because they cannot be observed directly (Maghfirah *et al.*, 2024).

The research results also show that technology-based intervention strategies have great potential in reducing misconceptions. Technology-based approaches such as interactive simulations and dynamic animations can help students understand abstract concepts better. Research by Suharto *et al.* (2020) shows that the use of interactive simulations increases student understanding by up to 75%. This simulation provides a dynamic visualization of orbital shapes, electron distribution, and interactions between subatomic particles. The use of multi-tiered diagnostic tests is also effective for identifying student misconceptions. These tests allow educators to find out specific parts of the concept that students do not understand. The results of this test can be used as a basis for designing more focused remedial learning.

Apart from technology-based strategies, problem-based learning (PBL) models are also effective in helping students overcome misconceptions. This model allows students to learn concepts in contexts that are relevant to everyday life. Lestari and Anggraeni (2022) reported that the application of PBL helped students understand the relationship between the concept of atomic structure and chemical reactions. Other research shows that the use of contextual learning media such as simple experiments and visual analogies can also improve students' understanding. For example, experiments on the spectrum of light can be used to explain the relationship between electron energy and their energy levels.

Misconceptions in chemistry about atomic structure occur in the atomic model section, students often experience misconceptions in describing the position and motion of electrons. They assumed that electrons moved in fixed circular paths, as described in Bohr's classical model of the atom. The correct understanding is that electrons do not have a fixed trajectory, but their existence is expressed in the form of orbitals which are probability regions. The quantum mechanical model explains that orbitals can have various shapes such as spherical, lobular, or other shapes, depending on the energy and angular momentum of the electron. Apart from that, misconceptions also occur in the aspect of the concept of electron configuration, students often misunderstand how to fill orbitals. The Aufbau principle states that electrons will fill the orbitals with the lowest energy first. Hund's principle states that electrons will fill empty orbitals in the same subshell before pairing. The Pauli exclusion principle states that in one orbital there cannot be two electrons with the same spin. Students often ignore or misunderstand these rules, so that the electron configurations they create do not match reality. Examples of common errors include filling the 2p orbital with two electrons before the 2s orbital is completely filled or filling two electrons with the same spin in one orbital.

Misconceptions about subatomic particles are also quite common. Students often assume that electrons have a mass comparable to protons or neutrons. The true fact is that the mass of electrons is much smaller than the mass of protons and neutrons. This error is often caused by disproportionate visual representation in textbooks or learning media. Pictures of atoms that show electrons, protons, and neutrons in the same size can reinforce this misperception. Another factor that influences misconceptions is the way the teacher delivers the material. Teachers often provide incomplete information or use inaccurate analogies. For example, depicting electrons like planets revolving around the sun can reinforce student misconceptions. A curriculum that does not provide enough time to explore basic concepts is also a cause of misconceptions. In general, chemistry learning in high school often focuses on memorizing facts and formulas rather than understanding concepts in depth.

Research results from various sources provide data that misconceptions about the concept of atomic structure occur at low levels up to complex concept levels (Wardhani *et al.*, 2016). In the concept of atomic composition, students experience a wrong understanding of the concept by assuming that the particles that make up atoms consist of electrons, protons and neutrons. Learners or students do not understand that the atomic nucleus is actually the nucleus that makes up protons and electrons. Furthermore, identified misconceptions occur when students assume that positive ions occur when electrons are received while negative ions occur when electrons are released, even though the correct concept is that positive ions occur when atoms release electrons and negative ions occur when atoms receive electrons. Misconceptions that occur at the basic level also occur in other terms such as isotopes, isobars and isotones. Students also experience misconceptions about the meaning of ions. Students have the understanding that ions are the building blocks of protons, electrons and neutrons, even though the correct concept is that ions are atoms that have an electrical charge because they receive or release electrons.

Technology-based interventions such as the use of dynamic simulations have great potential in addressing these misconceptions. Simulations can help students understand the dynamic and probabilistic properties of electrons in orbitals (Thomas *et al.*, 2019). Research by Wibowo et al. (2021) shows that the use of computer-based simulations increases students' understanding of atomic structure concepts by up to 80%. These simulations allow students to see changes in electron distribution in real-time as energy is added to or taken from an atomic system. Another successful approach is problem-based learning (PBL) (Susilaningsih & Musyarofah, 2020). This learning model directs students to solve real problems that require a deep understanding of the concept of atomic structure. For example, students may be asked to analyze the emission spectrum of a particular element and relate it to its electron configuration (A. Majid & Suyono, 2018). This approach not only helps students understand concepts, but also trains their critical and analytical thinking skills.

The results of this study provide important insight for teachers and curriculum developers regarding steps that can be taken to reduce misconceptions. One key step is to improve teacher training on effective teaching methods for abstract topics such as atomic structure (Malkawi *et al.*, 2018). Teachers need to be trained to use learning media that supports visualization, such as three-dimensional models, computer simulations and animated videos (Romadhona & Dwiningsih, 2021). The integration of three levels of chemical representation in learning is also very important. Teachers need to teach the concept of atomic structure by connecting macroscopic, submicroscopic and symbolic representations in an integrated manner (H. Majid et al., 2021). For example, to explain the concept of ionization energy, teachers can start with macroscopic phenomena such as metal evaporation, then explain electron interactions at the submicroscopic level, and finally use symbolic diagrams to depict energy changes.

The use of multi-tiered diagnostic tests is also highly recommended. This test allows teachers to find out the specific location of students' misconceptions and provide targeted feedback. This diagnostic test can be used periodically to monitor the development of student understanding and adjust learning strategies as needed (Damayanti & Priatmoko, 2023). Increasing understanding of the concept of atomic structure is very important because it is the basis for understanding other chemistry topics such as chemical bonds, periodic properties of elements, and chemical reactions. Errors in understanding atomic structure can have an impact on errors in understanding these topics. This study shows that a combination of the use of technology, contextual approaches, and appropriate evaluation strategies can significantly reduce student misconceptions. As a recommendation, further research is needed to develop more innovative and effective learning media. The use of Augmented Reality (AR) or Virtual Reality (VR) technology can be a promising option to help students understand abstract concepts.

CONCLUSION

Misconceptions that occur in the concept of atomic structure are found in various sections, down to the sub-concept level. Misconceptions occur in the concept of the atomic model, the quantum mechanical model, the Aufbau principle, Hund's principle, the Pauli exclusion principle, and even the subatomic concept of the composition of an atom. This misconception occurs due to several factors, both internal and external factors of students. Identification of these misconceptions is effective when using multi-tiered diagnostic test instruments. Misconceptions can be minimized by intensifying teacher training to be able to create technology-based learning media, visualization, animation, and a number of simulation interventions that support students' understanding of concepts.

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