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Reviewing The Literature on Students' Understanding About the Particulate Nature of Matter

Bhawana Mishra[1], Dr. Rakesh Kumar[2]

[1]Research Scholar,Department of Education, University of Delhi
[2]Assistant Professor, Department of Education, University of Delhi

Abstract:
This comprehensive review paper critically examines the existing body of research on the Particulate Nature of Matter (PNM) with a focus on identifying misconceptions and alternative frameworks at different academic levels. The studies encompass middle school, senior secondary, and higher education levels while also exploring teachers' perspectives on PNM. Understanding PNM is crucial for building a solid foundation in chemistry concepts, as it involves the use of atoms, molecules, and particles to enhance students' comprehension of the subject. Sufficient time and emphasis must be dedicated to teaching PNM to ensure its effective integration into the curriculum. Both students and teachers have been found to hold misconceptions that impede the desired levels of understanding in chemistry. Addressing these misconceptions early on is essential for successful learning outcomes. Recognizing the existing gaps in students' knowledge is vital as they bring their pre-existing concepts and knowledge to the classroom, necessitating instructors to build upon this foundation. Foundational concepts like matter, chemical reactions, solutions, and electrochemistry rely on a sound understanding of PNM. Thus, the analysis in this paper concentrates on studies in this specific area. Notably, there is a lack of PNM studies in the Indian context, particularly in schools in Delhi. Additionally, there is a need to compare students' understanding of PNM between grade 10 and grade 12. This research aims to address these gaps, attract attention to students' comprehension of PNM in Delhi schools, and contribute to a better understanding of the subject and the development of effective instructional strategies.

Key Words: Particulate Nature of Matter, Alternative Concepts, Teachers' Notions, Learners Ideas of PNM

1. Introduction:

The Particulate Nature of Matter (PNM) is a fundamental concept in the field of chemistry, serving as a building block for understanding various chemical phenomena. The understanding of PNM is essential for students to develop a strong foundation in chemistry concepts such as matter, chemical reactions, solutions, and electrochemistry. Through the use of atoms, molecules, and particles, students can construct mental models that facilitate a deeper comprehension of the subject matter.

Numerous studies have been conducted to investigate students' understanding of PNM across different academic levels, including middle school, senior secondary levels, and higher education levels. These studies have focused on identifying misconceptions and alternative frameworks held by students, aiming to bridge the gap between students' prior knowledge and the desired level of understanding in chemistry. Additionally, researchers have explored teachers' perspectives on PNM and their instructional practices related to teaching this crucial concept.

The findings from previous research emphasize the significance of allocating sufficient time and emphasizing the teaching of PNM in the chemistry curriculum. It has been observed that both students and teachers hold misconceptions that hinder the attainment of the desired level of understanding. Addressing these misconceptions at an early stage is vital to ensure students' progression in chemistry education.

Recognizing the existing gaps in students' knowledge is crucial as students bring their prior concepts and knowledge to the classroom. Instructors need to build upon this foundation, and a sound understanding of PNM is necessary to comprehend foundational concepts in chemistry. Matter, chemical reactions, solutions, and electrochemistry are examples of such concepts that rely on a solid grasp of PNM.

Despite the importance of understanding PNM, there is a noticeable lack of research studies focusing on this topic in the Indian context, particularly in schools in Delhi. This represents a significant gap in the literature, as it hampers our understanding of students' comprehension of PNM in this specific setting. Moreover, there is a need to compare students' understanding of PNM between grade 10 and grade 12 to identify potential developmental patterns and challenges in their understanding of this fundamental concept.

The primary objective of this research paper is to review the existing literature on students' understanding of PNM, encompassing studies conducted across different academic levels. The paper aims to identify common misconceptions and alternative frameworks held by students and examine teachers' perspectives on PNM and their instructional practices. Furthermore, this study seeks to explore the relationship between students' understanding of PNM and their performance in other chemistry concepts. Finally, the research intends to address the existing gaps in the literature by focusing on students' understanding of PNM in Delhi schools, aiming to shed light on the specific context and contribute to the broader understanding of this concept.

By analyzing and synthesizing the literature on students' understanding of PNM, this research paper aims to provide valuable insights that can inform educational practices and curriculum development in chemistry education. By addressing misconceptions, identifying effective instructional strategies, and recognizing the developmental patterns in students' understanding, this study aims to contribute to enhancing the quality of chemistry education and fostering a solid foundation in chemistry concepts for students in Delhi schools.

2. Research Objectives and Research Questions:

2.1 Research Objectives:

1. To review existing literature on students' understanding of the Particulate Nature of Matter (PNM) across different academic levels, including middle school, senior secondary levels, and higher education levels.
2. To identify common misconceptions and alternative frameworks held by students regarding PNM.
3. To examine teachers' perspectives on PNM and their instructional practices related to teaching PNM.
4. To explore the relationship between students' understanding of PNM and their performance in chemistry concepts such as matter, chemical reactions, solutions, and electrochemistry.

5. To investigate the differences in students' understanding of PNM between grade 10 and grade 12 in Delhi schools.

2.2 Research Questions:

1. What are the key findings from previous studies regarding students' understanding of PNM at different academic levels?
2. What are the most common misconceptions and alternative frameworks held by students in relation to PNM?
3. How do teachers perceive and approach the teaching of PNM in their classrooms?
4. Is there a correlation between students' understanding of PNM and their performance in chemistry concepts such as matter, chemical reactions, solutions, and electrochemistry?
5. What are the differences in students' understanding of PNM between grade 10 and grade 12 in Delhi schools?

3 Critical Review and Discussion:

Review of literature is an important aspect of any research. In the current study, the review of literature has served multiple purposes. Firstly, it has provided a foundation of knowledge on the topic of the particulate nature of matter. Additionally, it has helped identify areas of prior scholarship to avoid duplication of work and acknowledge other researchers. The review has also helped in identifying inconsistencies and gaps in the understanding of particulate structure of matter. Furthermore, examining existing literature has helped to justify the need for further research in this area and position the current study within the context of existing literature on the particulate nature of matter.

Consequently, this section presents summaries and synthesis of literature analyzed thematically:

3.1 Emphasis on teaching about the particulate nature of matter:

Research in science education highlights that students bring their existing concepts to the classroom, and new information needs to be integrated into their preexisting knowledge system (Ayas et al., 2010). Studies have demonstrated the effectiveness of instruction on the particulate nature of matter in facilitating students' understanding of the connections between the microscopic, macroscopic, and symbolic levels of chemistry (Ali, 2015). A solid grasp of the concept of matter is crucial for comprehending the principles and theories of physical and chemical changes, as chemistry extensively deals with the science of matter and its transformations (Liu & Lesniak, 2005). Failure to establish a strong foundation in the fundamentals of chemistry can impede students' ability to comprehend advanced concepts (Nakhleh, 1992). Thus, emphasizing the particulate nature of matter in early stages of schooling is essential for developing a thorough understanding of chemistry topics such as chemical reactions, bonding, phase changes, and their real-life applications.

These researches highlight the significance of integrating new information into students' pre-existing knowledge systems. Instruction on the particulate nature of matter has been shown to effectively enhance students' understanding of the interconnectedness between microscopic, macroscopic, and symbolic levels of chemistry. A solid understanding of matter is essential for comprehending principles and theories of physical and chemical changes, as chemistry revolves around the study of matter and its transformations. Failing to establish a strong foundation in chemistry fundamentals can hinder students' ability to grasp advanced concepts. This critical analysis underscores the importance of providing effective instruction on the particulate nature of matter to promote students' comprehensive understanding of chemistry.

3.2 Evidence of the particulate nature of matter:

Researchers have identified phenomena like diffusion, osmosis, Brownian movement, and the existence of molecules as indirect evidence supporting the particulate nature of matter. It is important to discuss these phenomena when explaining the concept to students (Becker, 2013). In their study on reasoning using the particulate nature of matter as a socio-chemical norm, the researchers argue that students' ability to relate particulate ideas to various thermodynamic concepts depends heavily on socially negotiated classroom criteria. They also suggest that students should not only possess a conceptual understanding of the particulate nature of matter but also be able to use particulate-level evidence to reason about chemical and physical properties. This entails constructing arguments using particulate-level ideas and representations (Ali, 2015).

The identified phenomena, including diffusion, osmosis, Brownian movement, and the existence of molecules, serve as indirect evidence supporting the particulate nature of matter. These phenomena are essential to discuss when teaching students about the concept. Becker (2013) emphasizes the importance of integrating these phenomena into explanations for students. Ali's (2015) study highlights that students' ability to connect particulate ideas with thermodynamic concepts depends on socially negotiated classroom criteria. It is suggested that students should possess not only a conceptual understanding of particulate nature but also the ability to use particulate-level evidence to reason about chemical and physical properties, requiring the construction of arguments using particulate-level ideas and representations. This critical analysis underscores the significance of incorporating real-world phenomena and social interactions in teaching and learning about the particulate nature of matter.

3.3 Promoting Students' Understanding of the Particulate Nature of Matter:

Research conducted by Singer et al. (2003) emphasizes the significance of project-based science in developing students' understanding of the particulate nature of matter. They assert that the particulate nature of matter is a fundamental concept that should be comprehensively understood by students at the middle school level. However, science education research reveals that secondary school students often struggle with grasping the structure of matter. Singer et al. conducted a study that demonstrated how an extended project-based unit improved urban middle school students' understanding of the particulate nature of matter and actively engaged them. Various forms of data, including pre- and posttests, interviews, students' drawings, and video recordings of classroom activities, were collected. The data analysis revealed that the majority of students significantly increased their content knowledge after participating in the learning activities. Furthermore, the findings indicated that students' understanding of the particulate nature of matter continued to improve over time, and their understanding was retained and reinforced when applying the concept. The researchers suggest that examining the design features of the curriculum and the teachers' use of multiple representations can provide insights into the effectiveness of the learning activities in the unit.

Similarly, Carr et al. (2013) conducted research focusing on effectively developing students' understanding of the particulate nature of matter through inquiry-based learning at the junior secondary level. Their intervention involving inquiry-based learning demonstrated a higher level of comprehension of the particulate nature of matter among the intervention group compared to their peers in the control group. The researchers employed Repertory Grid analysis to identify and rank aspects of the students' affective and cognitive learning experiences. This approach facilitated systematic measurement of students' comprehension of chemistry concepts and aided in detecting their learning progress.

In a review conducted by Plumley et al. (2016), multiple research articles were analyzed to identify effective methods of explaining the particulate nature of matter to elementary students. The Small Particle Model of Matter was found to be an effective approach in teaching elementary students about the particulate nature of matter. Similarly, the small particle model has been utilized when explaining concepts of atoms and molecules to middle and high school students.

3.4 Challenges in Understanding the Particulate Nature of Matter:

It is widely acknowledged that understanding the particulate nature of matter is fundamental to comprehending various topics in chemistry, including atomic structure, bonding, molecules, solution chemistry, chemical reactions, equilibrium, and chemical energetics. There exists a challenge in teaching macroscopic chemistry, which is often hands-on and seen as interesting by students, while simultaneously explaining macroscopic changes in terms of the behavior of submicroscopic particles. This challenge involves deciding how and when to address the three levels at which chemistry can be explained—macroscopic, submicroscopic, and/or symbolic—and whether students need to grasp the concept at each level (Johnstone, 1991). On one hand, modern theories regarding the structure of matter can be too complex or abstract for most secondary school students. On the other hand, ideas that students can understand may be considered naive or incorrect by experts. For instance, why should a particle, unlike any other object, lack its own temperature? A scientific explanation begins with minimal assumptions and builds from there, while a child starts from the comprehensive world of everyday life and gradually eliminates aspects such as temperature and color in a slow and challenging process to reach the same understanding (De Vos & Verdonk, 1996).

To address these challenges, teacher development programs are crucial in transforming teachers' perspectives on teaching and learning, as well as their instructional practices. Taber (2009) also discusses the difficulties arising from the symbolic language of chemistry. It is important for teachers to recognize that mastering the new language of chemistry takes time and practice for students. Therefore, teachers should allocate more time for students to understand and assimilate these concepts according to their individual pace of learning.

3.5 Existing understanding about the PNM amongst students and teachers:

Existing understanding about the Particulate Nature of Matter (PNM) among students and teachers has been a topic of investigation in scientific education. In school science, concepts such as atoms, molecules, and chemical reactions are used to explain various phenomena. However, since these interactions are not directly observable, learners often face difficulties in comprehending the nature of matter and its transformations (Andersson, 1990).

When students enter secondary-level classrooms, they bring with them pre-existing knowledge and ideas about the natural world based on their experiences. It is crucial to pay attention to their ideas, provide them with opportunities to express their conceptions, and build upon their existing knowledge to enhance classroom learning effectiveness (Driver et al., 1994). One research study examined the conceptions of evaporation and condensation among Year 1 and Year 6 students using group discussions, written responses, and interviews (Tytler, 2000).

Several challenges contribute to students' difficulties in understanding the particulate nature of substances in solid, liquid, and gas phases. These challenges include the abstract nature of the concept, inadequate explanations from teachers, vague explanations and representations in textbooks, and limited hands-on activities related to the concept (Riaz, 2004). Studies have indicated that elementary-age students often hold the misconception that matter is continuous rather than being composed of particles (Nakhleh &Samarapungavan, 1999). For instance, Nakhleh and Samarapungavan (1999) found that students perceive matter as purely macroscopic and continuous, lacking any underlying structure. Similarly, some students believe that gases, including air, are continuous (Merritt et al., 2008). As Séré (1986) reported, many pupils believed that air could not be transported, viewing it as a single mass. Young children often associate weight with how heavy something feels in relation to other objects (Snir et al., 2003). In certain studies, when asked about the outcome of repeatedly dividing a piece of Styrofoam, students imagined it getting smaller but assumed it would eventually have no weight because they could not feel it (Smith et al., 2005). Understanding that matter has weight, even if it cannot be felt, is crucial for distinguishing between extensive properties (e.g., weight and volume) and intensive ones (e.g., density).

Research on chemical bonding has revealed that students often encounter difficulties and develop misconceptions in this area. Concepts such as electrons, ionization energy, electronegativity, bonding, geometry, molecular structure, and stability are fundamental to chemistry, ranging from reactivity in organic chemistry to spectroscopy in analytical chemistry (Nicoll, 2001). It is essential for students to grasp these concepts to understand why and how chemical bonds occur. Buttsand and Smith (1987) reported that students were confused about covalent and ionic bonds, specifically regarding the unequal sharing and positioning of electron pairs in a covalent bond among Grade 11 and 12 students. These students associated electron sharing with covalent bonding but did not consider the influence of electronegativity and the resulting unequal electron sharing. TABER (1997) investigated students' understanding of basic bonding concepts and identified misconceptions related to covalent bonding, metallic bonding, resonance structures, coordinate bonding, hydrogen bonding, and van der Waals forces. Prodjosantoso et al. (2019) also explored students' misconceptions related to ionic bonding.

Researchers have studied students' understanding of the Particulate Nature of Matter at both secondary and tertiary levels. It has been observed that as student's progress in their education, their understanding of the PNM improves (Ayas et al., 2010).

Misconceptions among students about electrochemistry were identified by Greenbowe (1997) in a study involving six introductory college chemistry students after electrochemistry instruction. Common misconceptions observed included the belief that electrons flow through the salt bridge and electrolyte solutions to complete the circuit, assigning plus and minus signs to electrodes based on net electronic charges, and considering water as unreactive in the electrolysis of aqueous solutions. New misconceptions were also identified, including the notion that half-cell potentials are absolute and can be used to predict the spontaneity of individual half-cells, as well as the belief that electrochemical cell potentials are independent of ion concentrations. It is worth noting that despite these misconceptions, most students were still able to calculate cell potentials correctly. This finding aligns with previous research suggesting that students may be proficient in solving quantitative examination problems but lack a comprehensive understanding of the underlying concepts. The probable origins of these misconceptions were attributed to students' lack of awareness regarding the relative nature of electrochemical potentials and misleading or incorrect statements in chemistry textbooks.

Regarding students' responses related to concepts about the speed of particles and the spaces between particles during melting, cooling, and vaporizing, variations were observed. Some students believed that the distance between particles would not change during these events, while others thought that the distances between particles would increase or decrease. Similar results were also reported by Osborne and Cosgrove (1983). Although the number of students who believed there were no gaps between liquid and gas particles was low, many students held the misconception that there were no spaces between solid particles. Even though students could use the particulate model to describe phase changes, they still had some misconceptions. Pereira and Pestana (1991) found that many high school students had misunderstandings about the relative distance between particles in the three states. One possible reason for this misconception is that when explaining the structure of solids, it is often stated that the space between particles is generally none or very little, leading to the misconception that particles in a solid do not have any movement at all. This idea was also highlighted by Boz (2006) in a study where students believed that particles in a solid substance have no movement due to their close proximity to each other and the tight packing. These findings indicate that students struggle to effectively apply their understanding of the particulate nature of matter at the microscopic level to explain observable macroscopic properties of matter (HalukOzmen and Osman Kenan, 2007).

Additionally, Liu and Lesniak (2005) state in the literature that there is no clear conceptual leap between different grade levels in the progression of concepts related to matter. They argue that there is significant overlap in students' conceptions across different grades. Liu and Lesniak propose that concept development in children regarding matter follows five overlapping waves. The first wave involves the development of informal ideas about matter, such as properties and changes related to water and air, typically occurring by grade 3 or 4. The second wave occurs around grade 7 when students develop an understanding of matter conservation. The third wave, observed in general students from grades 8 to 12, is characterized by an understanding of physical and chemical properties and changes. The fourth wave focuses on the structural and compositional aspects of matter. The final wave involves explaining and predicting matter and changes using bonding theories. Treagust et al. (2002) add that only at the last level, students become fluent in representing and coordinating matter and changes at the macroscopic, symbolic, and microscopic levels. Considering this, it may be unreasonable to expect a conceptual leap between the 4th, 5th, and 6th grade in the context of this study.

Moreover, Valanides (2000) contributes to the literature review by discussing primary teachers' ideas about the particulate nature of matter (PNM). Teachers were presented with a distillation apparatus accompanied by a diagram, and its use was discussed. They were then asked to describe the macroscopic and microscopic changes that would occur when different water solutions were distilled. The majority of the teachers demonstrated limited understanding of the particulate nature of matter and the connection between observable macroscopic changes (e.g., evaporation or liquefaction) and the movement and interactions of molecules. They also struggled to develop appropriate concepts related to boiling point, latent heat of evaporation, and fractional distillation. Difficulties were more pronounced when considering distillation of salt solution, sugar solution, tap water, aqueous alcoholic solution, tea, and coke or wine. Similarly, Nakiboglu (2003) conducted a study on prospective chemistry teachers' conceptions of atomic orbitals, hybridization, and related concepts. The subjects completed a diagnostic test, responding to open-ended and multiple-choice questions about atomic orbitals and hybridization. The results revealed that individuals in the field of chemistry held some misconceptions regarding atomic orbitals, hybridization, and related concepts, which are crucial prerequisites for understanding hybridization.

In a study conducted by Kikas (2003), the conceptions of trainee, primary, and subject teachers regarding three phenomena were examined: the motion of objects, seasonal changes, and aggregate changes of matter. A total of 198 participants completed a questionnaire that included two types of tasks. Firstly, the teachers were asked to evaluate the adequacy of given explanations in comparison to their knowledge of contemporary scientific explanations. The explanations provided fell into four categories: a simple description, description with terms, an explanation with misconceptions, and a scientific explanation. Secondly, the participants answered multiple-choice questions and provided explanations to support their choices. The results revealed the presence of various misconceptions across the different phenomena and teacher groups, highlighting differences among them.

In the Indian context, Mondal (2012) conducted research on misconceptions in chemistry among ninth-grade students and explored remedial measures. The study revealed that students held misconceptions on various science concepts. It also emphasized the effectiveness of modeling in science teaching and how it could help address students' misconceptions (Sarikaya, 2007). Practical activities supported by science teaching were identified as alternative methods to traditional approaches for remedying misconceptions. However, the remediation of students' misconceptions requires well-trained teachers who themselves are free from misconceptions. Therefore, it is essential to provide comprehensive training to prospective teachers to equip them as experts who are aware of potential misconceptions. Prospective teachers, as well as their instructors and lecturers, should be knowledgeable about students' prior knowledge and misconceptions and understand the reasons behind these misconceptions. Successful teachers are those who are aware of their students' misconceptions and know how to address them.

Similarly, Aydeniz (2010) investigated the understanding of the particulate nature of matter among middle and high school students. The study included 87 students, consisting of 41 high school and 46 middle school students. The findings revealed misconceptions among students regarding the law of conservation of matter, chemical composition of matter in different phases, the process of condensation, and the behavior of molecules at a microscopic level. The study concluded that the pedagogical content knowledge (PCK) of science teachers needs enhancement.

In a separate study, Taber et al. (2010) discussed chemical phenomena that evoke intuitive notions and activate implicit knowledge elements in chemical contexts. These implicit knowledge elements relate more to the fundamental nature of the material world rather than an intuitive sense of mechanism. The study highlighted that specific properties of materials arise from their component parts, certain combinations of materials naturally react, and certain configurations are naturally preferred, leading to the spreading out of concentrated materials. Understanding these aspects can be improved by utilizing cognitive resources to explore the inner ideas held by students. Furthermore, Taber (2009b) discussed the difficulties learners face in understanding particle models in chemistry due to the activation of implicit knowledge elements that contradict canonical science, which states that substances have components giving rise to different properties. The activation of such implicit knowledge elements may present phenomena as natural and not in need of further explanation, which hinders students' understanding.

Interestingly, (Driver & Easley, 1978) conducted a study titled "Pupils and Paradigms," where they discussed the persistence of preconceptions despite instruction, supporting Ausubel's claim. Similarly, in their book "Making Sense of Secondary Science" (Driver et al., 2014), the authors provided evidence of alternative conceptions among students. They found that students often confuse the name of an object with the name of the material it is made of. Additionally, students struggle to differentiate between mixtures of substances and purity and face difficulties in understanding concepts such as conservation of matter, mass, and density. Students also demonstrate limited understanding of the solid, liquid, and gaseous states of matter, as well as processes like melting, freezing, evaporation, boiling, condensation, sublimation, and dissolving. Furthermore, students hold misconceptions regarding chemical change, combustion, decomposition, interaction, and conservation of matter. Their understanding of acids and bases is often based on sensory experiences

Conclusion:

In summary, we have discussed various studies conducted in the field of Particulate Nature of Matter (PNM). These studies have focused on identifying misconceptions and alternative frameworks at different academic levels, including middle school, senior secondary levels, and higher education levels. Additionally, teachers' perspectives on PNM have also been explored. The understanding of PNM is essential for building a strong foundation in chemistry concepts. The use of atoms, molecules, and particles in explanations contributes to a better understanding of the subject among students. It is crucial to allocate sufficient time and emphasize the teaching of PNM. Both students and teachers have been found to hold misconceptions that hinder the attainment of the desired level of understanding in chemistry. Therefore, finding solutions and addressing these misconceptions at an early stage is necessary. Recognizing the existing gaps in students' knowledge is crucial because students bring their prior concepts and knowledge to the classroom, and instructors need to build upon that foundation. In this regard, foundational concepts such as matter, chemical reactions, solutions, and electrochemistry require a sound understanding of PNM. Hence, we have focused our analysis on studies in this area. It is worth noting that there is a lack of PNM studies in the Indian context, particularly in schools in Delhi. Furthermore, there is a need to compare students' understanding of PNM between grade 10 and grade 12. Our research aims to address these gaps by exploring students' understanding of PNM in Delhi schools.

References

1. Ali, T. (2015). *particle nature of matter*. https://passnownow.com/classwork-series-physics-ss1-particle-nature-of-matter/
2. Andersson, B. (1990). Pupils' conceptions of matter and its transformations (age 12-16). In *Studies in Science Education* (Vol. 18, Issue 1). https://doi.org/10.1080/03057269008559981
3. Ayas, A., Özmen, H., & Çalik, M. (2010). Students' conceptions of the particulate nature of matter at secondary and tertiary level. *International Journal of Science and Mathematics Education*, *8*(1), 165–184. https://doi.org/10.1007/s10763-009-9167-x
4. Aydeniz, M. and E. K. (2010). what students know about particulate nature of matter. *School Science and Mathematics*, *112*(2), 59–66.
5. Becker, N. (2013). Reasoning using particulate nature of matter: An example of a sociochemical normin a university level physical chemistry class. *Chemistry Education: Research and Practice*, *14*(1), 81–94. http://library1.nida.ac.th/termpaper6/sd/2554/19755.pdf
6. Buttsand, B., & Smith, R. (1987). *Percei Ved Difficulty Rank Order " Percentage "*. 192–201.
7. De Vos, W., & Verdonk, A. H. (1996). The Particulate Nature of Matter in Science Education and in

Science. *Journal of Research in Science Teaching*, *33*(6), 657–664. https://doi.org/10.1002/(SICI)1098-2736(199608)33:6<657::AID-TEA4>3.0.CO;2-N

8. Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing Scientific Knowledge in the Classroom. *Educational Researcher, 23*(7), 5–12. https://doi.org/10.3102/0013189X023007005
9. Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education*, *5*(1), 61–84. https://doi.org/10.1080/03057267808559857
10. Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (2014). Making Sense of Secondary Science. *Making Sense of Secondary Science*. https://doi.org/10.4324/9781315747415
11. Greenbowe, M. J. S. T. J. (1997). misconceptions in electrochemistry. *Journal of Research in Science Teaching*, *34*(4), 377–398.
12. Haluk Ozmen and osman Kenan. (2007). ozmen and kanan. *Asia-Pacific Forum on Science Learning and Teaching*, *8*(1), 16.
13. Johnstone, A. H. (1991). Why is Chemistry Difficult to Learn? Things are Seldom What They Seem. *Journal of Computer Assisted Learning*, *7*, 75–83.
14. Kikas, E. (2003). teachers conceptions and misconceptions concerning three natural phenomena. *Journal of Research in Science Teaching*, *41*(5), 432–448.
15. Liu, X., & Lesniak, K. M. (2005). Students' progression of understanding the matter concept from elementary to high school. *Science Education*, *89*(3), 433–450. https://doi.org/10.1002/sce.20056
16. Merritt, J. D., Krajcik, J., & Shwartz, Y. (2008). Development of a learning progression for the particle model of matter. *Computer-Supported Collaborative Learning Conference, CSCL*, *PART 2*, 75–81.
17. Mondal, A. C. and B. C. (2012). understanding misconceptions in chemistry at 9th grade. *Indian Streams Research Journal*, *2*(7), 1–9.
18. Nakhleh, M. B., & Samarapungavan, A. (1999). Elementary school children's beliefs about matter. *Journal of Research in Science Teaching*, *36*(7), 777–805. https://doi.org/10.1002/(SICI)1098-2736(199909)36:7<777::AID-TEA4>3.0.CO;2-Z
19. Nakiboglu, C. (2003). instructional misconceptions of Turkish Prospective chemistry teachers about atomic orbitals and hybridization. *Chemistry Education Research and Practice*, *4*, 171–188.
20. Osborne, R. J., & Cosgrove, M. M. (1983). Children's conceptions of the changes of state of water. *Journal of Research in Science Teaching*, *20*(9), 825–838. https://doi.org/10.1002/tea.3660200905
21. Plumley, C. L., Smith, P. S., Esch, R. K., & Horizon Research, I. (2016). A Review of the Research Literature on Teaching about the small particle model of matter to elementary students. *Horizon Research, Inc., september*. http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=ED587207&site=ehost-live
22. Prodjosantoso, A. K., Hertina, A. M., & Irwanto. (2019). The misconception diagnosis on ionic and covalent bonds concepts with three tier diagnostic test. *International Journal of Instruction*, *12*(1), 1477–1488. https://doi.org/10.29333/iji.2019.12194a
23. Riaz, M. (2004). Helping children to understand particulate nature of matter. *Alberta Science Education Journal*, *36*(2), 56.
24. Sarikaya, M. (2007). Prospective teachers' misconceptions about the atomic structure in the context of electrification by friction and an activity in order to remedy them. *International Education*

Journal, *8*(1), 40–63.
25. Séré, M. G. (1986). Children's conceptions of the gaseous state, prior to teaching. *European Journal of Science Education*, *8*(4), 413–425. https://doi.org/10.1080/0140528860080408
26. Singer, J. E., Tal, R. T., & Wu, H.-K. (2003). Students' Understanding of the Particulate Nature of Matter. *School Science and Mathematics*, *103*(1), 28–44. https://doi.org/10.1111/j.1949-8594.2003.tb18111.x
27. Smith, C. L., Solomon, G. E. A., & Carey, S. (2005). Never getting to zero: Elementary school students' understanding of the infinite divisibility of number and matter. *Cognitive Psychology*, *51*(2), 101–140. https://doi.org/10.1016/j.cogpsych.2005.03.001
28. Snir, J., Smith, C. L., & Raz, G. (2003). Linking Phenomena with Competing Underlying Models: A Software Tool for Introducing Students to the Particulate Model of Matter. *Science Education*, *87*(6), 794–830. https://doi.org/10.1002/sce.10069
29. TABER, K. (1997). Student understanding of ionic bonding : molecular versus electrostatic framework ? *School Science Review*, *78*(285), 85–95.
30. Taber, K. S. (2009a). *Learning at the Symbolic Level* (Issue January 2009). https://doi.org/10.1007/978-1-4020-8872-8_5
31. Taber, K. S. (2009b). *Learning at the Symbolic Level*. https://doi.org/10.1007/978-1-4020-8872-8_5
32. Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2002). Students' understanding of the role of scientific models in learning science. *International Journal of Science Education*, *24*(4), 357–368. https://doi.org/10.1080/09500690110066485
33. Tytler, R. (2000). A comparison of year 1 and year 6 students' conceptions of evaporation and condensation: Dimensions of conceptual progression. *International Journal of Science Education*, *22*(5), 447–467. https://doi.org/10.1080/095006900289723
34. VALANIDES, N. (2000). alanides. *Chemistry Education Research and Practice in EUROPE*, *1*(3), 355–364.
35. Ali, T. (2015). *particle nature of matter*. https://passnownow.com/classwork-series-physics-ss1-particle-nature-of-matter/
36. Andersson, B. (1990). Pupils' conceptions of matter and its transformations (age 12-16). In *Studies in Science Education* (Vol. 18, Issue 1). https://doi.org/10.1080/03057269008559981
37. Ayas, A., Özmen, H., & Çalik, M. (2010). Students' conceptions of the particulate nature of matter at secondary and tertiary level. *International Journal of Science and Mathematics Education*, *8*(1), 165–184. https://doi.org/10.1007/s10763-009-9167-x
38. Aydeniz, M. and E. K. (2010). what students know about particulate nature of matter. *School Science and Mathematics*, *112*(2), 59–66.
39. Becker, N. (2013). Reasoning using particulate nature of matter: An example of a sociochemical normin a university level physical chemistry class. *Chemistry Education: Research and Practice*, *14*(1), 81–94. http://library1.nida.ac.th/termpaper6/sd/2554/19755.pdf
40. Buttsand, B., & Smith, R. (1987). *Percei Ved Difficulty Rank Order " Percentage "*. 192–201.
41. De Vos, W., & Verdonk, A. H. (1996). The Particulate Nature of Matter in Science Education and in Science. *Journal of Research in Science Teaching*, *33*(6), 657–664. https://doi.org/10.1002/(SICI)1098-2736(199608)33:6<657::AID-TEA4>3.0.CO;2-N
42. Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing Scientific Knowledge in the Classroom. *Educational Researcher*, *23*(7), 5–12.

https://doi.org/10.3102/0013189X023007005
43. Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education*, *5*(1), 61–84. https://doi.org/10.1080/03057267808559857
44. Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (2014). Making Sense of Secondary Science. *Making Sense of Secondary Science*. https://doi.org/10.4324/9781315747415
45. Greenbowe, M. J. S. T. J. (1997). misconceptions in electrochemistry. *Journal of Research in Science Teaching*, *34*(4), 377–398.
46. Haluk Ozmen and osman Kenan. (2007). ozmen and kanan. *Asia-Pacific Forum on Science Learning and Teaching*, *8*(1), 16.
47. Johnstone, A. H. (1991). Why is Chemistry Difficult to Learn? Things are Seldom What They Seem. *Journal of Computer Assisted Learning*, *7*, 75–83.
48. Kikas, E. (2003). teachers conceptions and misconceptions concerning three natural phenomena. *Journal of Research in Science Teaching*, *41*(5), 432–448.
49. Liu, X., & Lesniak, K. M. (2005). Students' progression of understanding the matter concept from elementary to high school. *Science Education*, *89*(3), 433–450. https://doi.org/10.1002/sce.20056
50. Merritt, J. D., Krajcik, J., & Shwartz, Y. (2008). Development of a learning progression for the particle model of matter. *Computer-Supported Collaborative Learning Conference, CSCL, PART 2*, 75–81.
51. Mondal, A. C. and B. C. (2012). understanding misconceptions in chemistry at 9th grade. *Indian Streams Research Journal*, *2*(7), 1–9.
52. Nakhleh, M. B., & Samarapungavan, A. (1999). Elementary school children's beliefs about matter. *Journal of Research in Science Teaching*, *36*(7), 777–805. https://doi.org/10.1002/(SICI)1098-2736(199909)36:7<777::AID-TEA4>3.0.CO;2-Z
53. Nakiboglu, C. (2003). instructional misconceptions of Turkish Prospective chemistry teachers about atomic orbitals and hybridization. *Chemistry Education Research and Practice*, *4*, 171–188.
54. Osborne, R. J., & Cosgrove, M. M. (1983). Children's conceptions of the changes of state of water. *Journal of Research in Science Teaching*, *20*(9), 825–838. https://doi.org/10.1002/tea.3660200905
55. Plumley, C. L., Smith, P. S., Esch, R. K., & Horizon Research, I. (2016). A Review of the Research Literature on Teaching about the small particle model of matter to elementary students. *Horizon Research, Inc., september*. http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=ED587207&site=ehost-live
56. Prodjosantoso, A. K., Hertina, A. M., & Irwanto. (2019). The misconception diagnosis on ionic and covalent bonds concepts with three tier diagnostic test. *International Journal of Instruction*, *12*(1), 1477–1488. https://doi.org/10.29333/iji.2019.12194a
57. Riaz, M. (2004). Helping children to understand particulate nature of matter. *Alberta Science Education Journal*, *36*(2), 56.
58. Sarikaya, M. (2007). Prospective teachers' misconceptions about the atomic structure in the context of electrification by friction and an activity in order to remedy them. *International Education Journal*, *8*(1), 40–63.
59. Séré, M. G. (1986). Children's conceptions of the gaseous state, prior to teaching. *European Journal of Science Education*, *8*(4), 413–425. https://doi.org/10.1080/0140528860080408
60. Singer, J. E., Tal, R. T., & Wu, H.-K. (2003). Students' Understanding of the Particulate Nature of

Matter. *School Science and Mathematics*, *103*(1), 28–44. https://doi.org/10.1111/j.1949-8594.2003.tb18111.x

61. Smith, C. L., Solomon, G. E. A., & Carey, S. (2005). Never getting to zero: Elementary school students' understanding of the infinite divisibility of number and matter. *Cognitive Psychology*, *51*(2), 101–140. https://doi.org/10.1016/j.cogpsych.2005.03.001
62. Snir, J., Smith, C. L., & Raz, G. (2003). Linking Phenomena with Competing Underlying Models: A Software Tool for Introducing Students to the Particulate Model of Matter. *Science Education*, *87*(6), 794–830. https://doi.org/10.1002/sce.10069
63. TABER, K. (1997). Student understanding of ionic bonding : molecular versus electrostatic framework ? *School Science Review*, *78*(285), 85–95.
64. Taber, K. S. (2009a). *Learning at the Symbolic Level* (Issue January 2009). https://doi.org/10.1007/978-1-4020-8872-8_5
65. Taber, K. S. (2009b). *Learning at the Symbolic Level*. https://doi.org/10.1007/978-1-4020-8872-8_5
66. Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2002). Students' understanding of the role of scientific models in learning science. *International Journal of Science Education*, *24*(4), 357–368. https://doi.org/10.1080/09500690110066485
67. Tytler, R. (2000). A comparison of year 1 and year 6 students' conceptions of evaporation and condensation: Dimensions of conceptual progression. *International Journal of Science Education*, *22*(5), 447–467. https://doi.org/10.1080/095006900289723
68. VALANIDES, N. (2000). alanides. *Chemistry Education Research and Practice in EUROPE*, *1*(3), 355–364.