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Steinbuch's Epistemological Model and the Reality of Particles: A Philosophical Perspective for Chemistry Education

Almubarak[1], Nahadi[2]✉, Galuh Yuliani[3], Corrienna Abdul Talib[4], Dini Noor Arini[5]
[1,2,3]Study Program of Science Education, Universitas Pendidikan Indonesia, Indonesia
[1]Faculty of Teacher Training and Education, Universitas Lambung Mangkurat, Indonesia
[4]Faculty of Social Sciences and Humanities, Universiti Teknologi Malaysia, Malaysia
[5]College of Education, Washington State University, USA

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Abstract

Atoms are considered entities that independently originate from human thought and perception based on a materialist perspective. In terms of the scientific model concept, steinbuch created a scheme to indicate the epistemological process in science called "thinking in model terms." This scheme is the basis for understanding matter as reality. The purpose of the study is to explain the philosophical review of the study of the concept of particles as matter. This review can make students and teachers aware of the importance of a thinking model for understanding science. The implementation of the study used "reviewing the literature" with theoretical interventions from various literatures through five stages, namely identifying vital terms, locating literature, critically evaluating and selecting the literature for your review, organizing the literature, and writing a literature review. The study results show that a philosophical review of the understanding of particles as matter that is real is an essential component of holistically understanding science. Understanding based on Steinbuch's scheme, "thinking in model terms," significantly impacts civilization, including chemistry education. The scheme's application also trains participants' representational abilities, especially at the particulate level, so that the chemistry knowledge obtained is meaningful to participants.

Keywords: chemistry education, epistemological process, quality education, representational abilities, science education, steinbuch's epistemological model

Corresponding Author:
Nahadi, Program Study of Science Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
Email: nahadi@upi.edu

1. Introduction

Atomism "Democritus and Leucippus" consider matter (atoms) the primary units that build the universe. Leucippus is regarded as the founder of atomism, later developed by his student, Democritus. According to Leucippus, the world is divided into two entities: "atoms are inseparable particles that makeup everything and empty space," and "empty space is the nothingness that exists between atoms." Democritus argued that atoms are the units that build reality (Melsen, 2023). Their ideas are similar to the modern atomic theory that an atom is the smallest unit and cannot be divided.

Ontologically, atoms are considered entities that independently originate from human thought or perception based on a materialist perspective. Another understanding is that matter consists of atoms and the laws of nature that govern the interactions between atoms. The findings of Leuikippos and Democritus were continued by the discovery of modern atomic theory called quantum mechanics. Modern atomic theory states that atoms are composed of tiny particles called subatoms, such as neutrons (n), protons (p), and electrons (e) (Barke et al., 2012; Melsen, 2023; Petrucci et al., 2011). Subatomic neutrons and protomes are nuclei surrounded by electrons at the speed of light. Another basis for modern atomic theory is particle dualism derived from the Heisenberg uncertainty principle and the Schrodinger equation.

This idea is reinforced by various modern atomic theories in physics and chemistry, emphasizing that atoms have an objective existence naturally present in human thought. This view is the basis for understanding the universe, and all contexts of phenomena, including the existence of atoms, can be explained through the properties and behavior of matter (Barke et al., 2009, 2012). In this discussion, atoms are considered fundamental components of matter, and all phenomena in the universe can be derived from the properties and interactions of atoms (Vallabhajosula, 2023). Therefore, the existence of atoms is seen as a construction of human thought, but that does not mean that atoms do not exist independently. Instead, the concepts and models of atoms result from human constructive activity in understanding the universe.

The atomic model is a gateway to changing how humans can understand matter in imagination and form. The concept of particles is the correct answer to understanding the existence of a form of matter because studying particles is the basis for understanding the reality of matter. Conceptually, matter is associated with pure matter from a particular type of particle. At the same time, the "ball" shape depicts matter (Barke et al., 2009). For example, the expert imagines that one ball is a particle of water and the other is a sugar particle. The mixture of the two balls produces the meaning that sugar dissolves in water. One can use the term "particle" to refer to atoms, ions, and molecules, depending on the context of the particles referred to and interpreted. Imaginarily, of course, atoms, ions, and molecules are not physically visible, and neither are the structures, reactions, and bonds that occur. These findings come from interpretation and reflection based on observations of various substances' properties and chemical reactions. The ball shape makes it easier to understand the existence of matter visually, even though the essence of the form of matter is much more complex, as described by Bohr (Barke et al., 2012; Petrucci et al., 2011; Vallabhajosula, 2023).

Proof that atoms are fundamental particles was put forward by Bent (1984) through his observations on melted sulfur particles (Bucat & Mocerino, 2009). According to Bent, a demonstration is the most original medium for understanding scientific terminology through the mind's eye. Melting sulfur contains two worlds, namely the macroscopic and sub-microscopic worlds, on the basis that the existence of atoms is in the sub-microscopic world (Becker et al., 2015; Gkitzia et al., 2020; Schwedler & Kaldewey, 2020). This particulate review can only be accessed through one's chemical imagination, while its reality is proven through the macro world or what is physically visible. Bent's (1984) thinking was demonstrated by Johnston's (1982) thinking about the existence of a hallucinatory entity in reality, namely representation (Taber, 2013). For example, in gas pressure (macro), submicroscopically, particles are colliding against the vessel's walls. In addition, the melting process is in a macro context, while the sub-micro process is at a high temperature enough to give particles the energy to overcome intermolecular forces.

Teaching chemistry is a complex subject that requires a certain level of knowledge and skills to understand. Students (Annisa et al., 2024; Ijirana et al., 2021; Ijirana & Wahyuni, 2019). Associated with the teaching of chemistry, that the main target of learning is not only to bring students at a high cognitive level but also how students interpret and internalize experiences that have been experienced while learning to become valuable individuals (Winarti et al., 2023; Winarti & Mubarak, 2019). Bent's (1984) rationale is that teachers teach chemistry content through various modeling methods, including content delivery skills and the importance of modeling. Modeling refers to how a person understands a context using the submicroscopic level (Bent, 1984; Bucat & Mocerino, 2009). Research by Justi & Gilbert (2002) also emphasized that a person's macro and sub-micro abilities are very helpful in constructing a scientific mental model, meaning that Bent's (1984) findings are essential. Bent's (1984) experiment is a form of modeling that helps humans understand that the nature of matter is at the particulate level (Barke et al., 2012; Bucat & Mocerino, 2009; Demirdöğen et al., 2023; Justi & Gilbert, 2002; Locatelli & Davidowitz, 2021).

Stachiowiak (1965) in Barke et al., (2009) explained that the concept of models is generally divided into three basic types. First, "image traits" is a model that always depicts something naturally or artificially. Second, "shortening traits" is a model that does not represent all aspects of the original but depends on the developer or user. Third, "subjective traits" is a model that describes the understanding of representation and its substitution, but only on certain subjects that are limited by specific theories or realities. In terms of the concept of a scientific model, Steinbuch (1977) in Barke et al., (2009) created a scheme to indicate the epistemological process in science called "thinking in model terms." The scheme explains that all forms of complex real problems, as they are, are recreated through certain perceptions as abstract models. A model of thinking using only relevant essential things has also been developed by Novick & Nussbaum (1978) to show that an atom is an entity field (Cheng & Gilbert, 2009b). Then, certain information or recognized rules of logic/physics can be added to the construction. This abstract thinking model can project reality back into reality by constructing a concrete model (Adbo & Taber, 2009; Schwedler & Kaldewey, 2020; Suja et al., 2020).

Regarding the scheme by Steinbuch (1977) in Barke et al., (2009), "thinking in model terms" is the most superior contribution to changing the human perspective on the existence of particles. An abstract definition is a form of someone's understanding that particles are not a reality, while Bent's (1984) thinking is that molecular interactions are a reality. The basis of Bent's (1984) previous understanding emphasized that in one context of phenomena, the existence of atomic particles is a form of reality. Bent's (1984) discovery found it difficult for someone to understand particles at the particulate level, so a medium was needed to explain atoms easily (Barke et al., 2009, 2012). Steinbuch (1977) in Barke et al., (2009) scheme contributed to the ease of understanding the form of particles (Barke et al., 2012). The most significant contribution was the transformation of mental models due to Steinbuch (1977) in Barke et al., (2009) modeling. Research by Werner et al., (2019) explains that the presence of a model greatly helps someone train their reasoning ability to understand the context. The findings of Werner et al (2019) follow the explanation of Johnstone et al., (1982, 2000) that understanding can be transformed by using models so that progress occurs and a scientific mental model is formed for a context.

Students tend to find it easier to build mental models by introducing natural phenomena and then being able to continue the model structure continuously (Barke et al., 2009, 2012). The inability to see particles is a fundamental reason for developing mental models through thinking in the context of science learning (Barke et al., 2012; Schwedler & Kaldewey, 2020; Sunyono, 2018). For instance, Lémery developed a particle model of the effects of acid with the understanding that "all acids consist of particles like bite points; all experiences show that acids cause pricks that everyone can feel on the tongue." Lémery had never seen acid particles, but he tried to transfer the macroscopic characteristics of acid to the mental model cited (Barke et al., 2012). In conclusion, mental structures and models are essential to understanding science, especially chemistry. The primary key of chemistry education is to characterize and diagnose mental models into a scientific model. The purpose of the study is to explain the philosophical review of the study of the concept of particles as matter.

2. Method

The study implementation procedure used was "reviewing the literature" with theoretical interventions from various pieces of literature (Creswell, 2012). The primary references in the review consisted of three references: misconceptions in chemistry (Barke et al., 2009), essentials in chemical education (Barke et al., 2012), and Introduction: Macro, Submicro, and Symbolic Representations and the Relationship Between Them: Key Models in Chemical Education. (Cheng & Gilbert, 2009a). However, additional references were also used so that the study could achieve knowledge optimization so that readers could quickly examine the orbital thinking about mental models in the context of chemical education. There are five main procedures for implementing the study as illustrated in Figure 1.

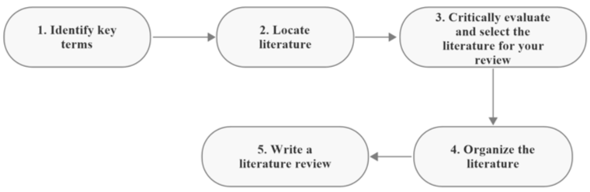

Figure 1. The Procedure for Conducting a Literature Study (Creswell, 2012)

First, "identify key terms" is the stage of selecting keywords that are the survey's target so that it is easy to conduct a review. The terminology used in the estuary is atomism, structure and mental models, chemical representation, abstract thinking, and atomic entities. Second, "locate literature" searches for literature or references related to the selected keywords. Hence, the decision is that the studies of Barke et al., (2009, 2012), and Bucat & Mocerino (2009) are the mainstays in the survey. Then, "critically evaluate and select the literature for your review" is to review the suitability and relevance of the study with the literature used.

Regarding the review, the literature used is very relevant to the previous keywords, making it easier to develop the study. Keyword dissection can be found in the references used. For example, atomism is found in the book by Barke et al., (2009). The study of mental models is found in the study by Barke et al., (2012), while others are in the "book chapter" in the chapter by Bucat &

Mocerino (2009) related to the theory of abstract thinking and the concept of representation. The next stage is "organize the literature," compiling or organizing the review results. The final stage is to elaborate and write the literature review results by paying attention to writing style, content structure, etc., or "write a literature review."

In theory, this study has great potential to be the primary reference in changing students' views on science, especially chemistry. A person's view helps form a scientific mental model, considering that participants tend to experience misunderstandings in learning science due to initial knowledge that is not transformed. Failure to achieve an understanding of the appropriate terminology is the result of the failure to form a scientific mental model. Teachers can use this study to develop chemistry learning at various levels of education. The expected cognitive outcome of learning chemistry is that participants understand that particles are a reality and exist in human life. Chemistry learning by adopting these findings can be a bridge of knowledge so that scientific understanding is fulfilled in participants' minds.

Scientifically constructed understanding requires a proper and concrete foundation. The use of literature in this research is the ideal foundation for introducing and showing that particle studies are a crucial part of studying chemistry. The literature adopts theories and research results relevant to the studied issues. This study can also be scientific material for all groups, considering that understanding science considerably helps educate someone about science.

3. Result and Discussion

Historically, the initial postulate came from John Dalton (1808) in Brock (1992), who used his symbols to represent a compound's atomic structure visually. His depiction is called the New System of Chemical Philosophy, consisting of 21 elements and 17 simple molecules. However, regarding thought, Democritus and Leukippos (460 BC-370 BC) state that atoms are minor elements that form reality, but their size is so small that humans cannot witness them. Democritus also explained that what happens to atoms is a movement, with the analogy of the movement of dust in all directions when sunlight enters a pitch-dark room. The ease of understanding material entities requires additional intervention in visual mode, so it is crucial to have a reference when understanding content through a scheme.

In terms of the scientific model concept, Steinbuch (1977) in Barke et al., (2009) created a scheme to indicate the epistemological process in science called "thinking in model terms." Steinbuch (1977) in Barke et al., (2009) found that all complex real-world problems, as the original, are created or redeveloped through certain perceptions as abstract models, but only with a thinking model that uses relevant essentials. In application, the depiction of the model requires additional references so that this information or a certain level of logic generally recognized is needed. So, to form a perception, a person already has a model for the thinking process at the next stage. The abstract thinking model can project back to reality by constructing a concrete model. This model contains irrelevant attachments, while the model should not contain irrelevant attachments (Barke et al., 2009).

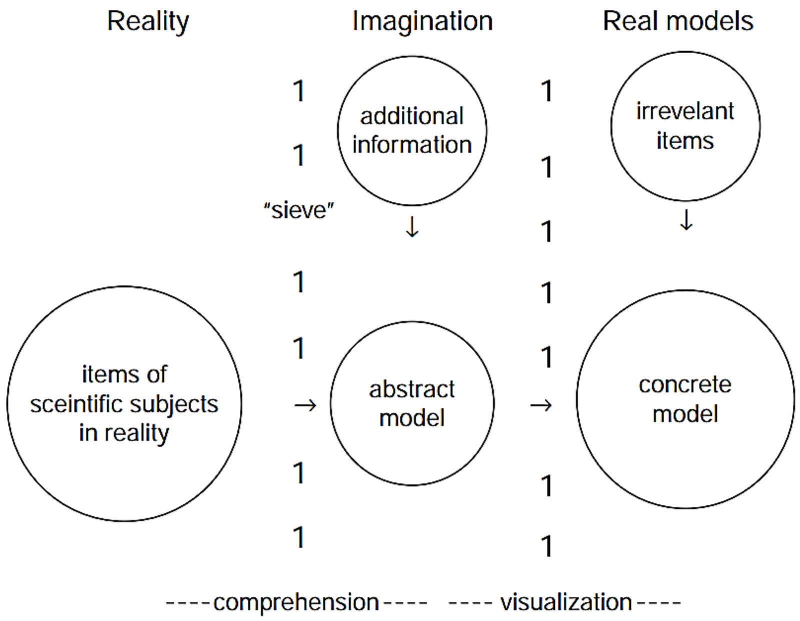

Figure 2. Scheme of "Thinking in Model Terms" by Steinbuch (1997) (Barke et al., 2009)

For example, the "thinking in models" scheme can be conveyed through the perception of Max von Laue, who in 1912 confirmed the theory of the 3-dimensional crystal lattice structure using X-ray beams. The interference pattern of sodium chloride crystals is part of the original model, namely the pattern formed through the interference and diffraction of the formed X-ray beam, and this situation is an important part that requires the process of filtering information. Furthermore, the diffraction of light in a two-dimensional lattice and its calculations have been known since Laue's time (an additional piece of information). They have become the basis for Laue's calculations of the three-dimensional diffraction lattice from X-ray experiments. As a result, experts formulated a spatially symmetric ion structure model in salt crystals (an abstract mental model). Laue proposed using realistic models to visualize the concept better. Still, it requires irrelevant objects such as balls, sticks, and glue to create a collection of nearby balls or a spatial lattice model (concrete model). Laue's findings (1912) in Barke et al., (2009) are an epistemological manifestation of what Steinbuch (1977) in Barke et al., (2009) sketched about matter as an actual entity.

In scientific perception, the model's movement starts from "left to right" based on the Steinbuch scheme. An expert usually does this scheme, but it is not recommended for beginners just starting to think about modeling (Barke et al., 2009). Participants are more likely to be directed from "right to left" after they are introduced to the natural phenomenon. The initial stage requires concrete models so that participants can develop further mental models and approach the model in terms of material structure. For example, salt crystals can be depicted using materials and interventions of ball colors, glue, and other detailed components that are considered irrelevant. Furthermore, participants can demonstrate the crystal lattice model based on the model made, namely the position of the ions involved in the lattice. Through discussion and comparison of various models, someone can experience ease in understanding the arrangement and size of ions in sodium chloride crystals (Barke et al., 2009).

Regarding the movement of the model from "left to right" in Figure 2 and the visualization of the experiment in Figure 3, a non-expert must understand the particles by understanding from "right to left." On the right side, participants can use aids, as shown in Figure 3 (balls, glue, etc.). The presence of aids helps students begin to understand the form of particles, and situations are assessed by providing models/modeling (Barke et al., 2009, 2012). By forming particles from the provision of tools, participants can imagine, especially how the structure of compounds in salt crystals. After that, the mental model's formation is compared with the results of natural experiments conducted by Laue (Figure 3). Lause's experiment shows that students can understand the content of scientists' experiments through modeling from "right to left," not "left to right."

Concrete models are needed to develop mental models and successfully arrive at appropriate models regarding the structure of the matter (Barke et al., 2012; Rusmansyah et al., 2021; Winarti et al., 2021). For example, one can use a close-packing model to demonstrate and discuss the crystal structure of a standard salt and the sizes of the ions involved, i.e., the material and color of the balls, the glue, and the gaps in the packing should be considered irrelevant details. Afterward, one can demonstrate a crystal lattice model that shows only the ions' positions. The balls' and sticks' material or color are irrelevant. Through discussion and comparison of these models, we can give young people an idea of the arrangement and sizes of the ions in a sodium chloride crystal (Barke et al., 2009).

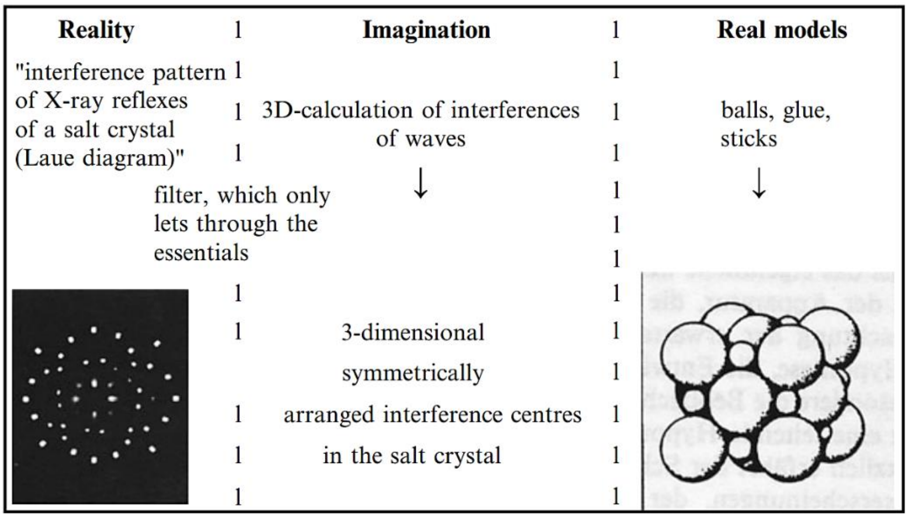

Figure 3. Scheme "Thinking in Model Terms," an Example of Laue's Path of Perception (Barke et al., 2009)

After forming the model framework through the thought process, the understanding of matter at the particle level experiences movement, collision, pressure, bonding, and interaction. Novick & Nussbaum (1978) experimented by asking participants to draw a gas diagram at the submicroscopic level and also presenting a diagram depicting a particle model to the participants. Then, the participants were asked to choose the one closest to their conception (See Figure 4 for representations before and after half of the gas is removed).

In the investigation process (Figure 4), the diagram describes aspects of the particle model such as: (1) gas consists of invisible particles, (2) gas particles are evenly distributed in every closed space, (3) there is "empty space" between particles in gas, and (4) particles in gas move intrinsically, not driven externally. Participants can digest the statement algorithmically, but their mental models cannot grow thoroughly and scientifically. For example, in the idea of "empty space" in a statement (3), the situation can produce multiple interpretations so that participants think that all diagram presentations have free space. The conclusion is that using diagrams as a medium of external and alternative representation is the best way to validate participants' internal representations. This means that the relationship between the existence of particles and empty space can only be accessed cognitively through visual representation to obtain a definite perspective (Bruce et al., 2022; Cheng & Gilbert, 2009b; Schwedler & Kaldewey, 2020; Trivic & Milanovic, 2018; Underwood et al., 2021).

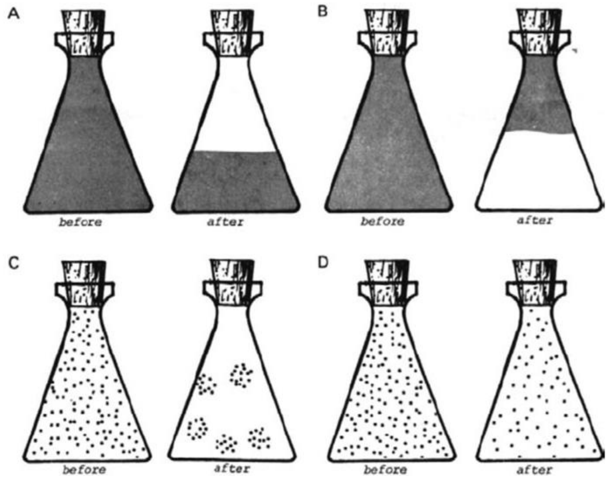

Figure 4. Part of the Diagram Presented to Participants in Novick & Nussbaum's (1978) Experiment (Cheng & Gilbert, 2009b)

The best intervention in constructing mental models is using chemical representation concepts (Barke et al., 2012). For example, molecules of a substance can be represented in various ways to illustrate specific characteristics of the existence of matter so that, for beginners, these molecules can appear as different structures (Bucat & Mocerino, 2009). The framework of the Steinbuch (1977) in Barke et al., (2009) discovery model is relevant to Johnstone (1982, 2000) regarding the reality of a material that can be understood through 3 levels, namely macroscopic, sub-microscopic, and symbolic (Barke et al., 2009, 2012; Bucat & Mocerino, 2009; Gkitzia et al., 2020; Taber, 2002). Macroscopic can be viewed from laboratory activities by demonstrating a substance whose results can be observed (Tsaparlis, 2021). At the same time, sub-microscopic and symbolic are viewed from the particulate level, such as depicting molecular structures and the reaction pathways that occur, including the use of atomic symbols, ions, and chemical bonds (Davidowitz & Chittleborough, 2009; Kapici, 2023; Keiner & Graulich, 2021).

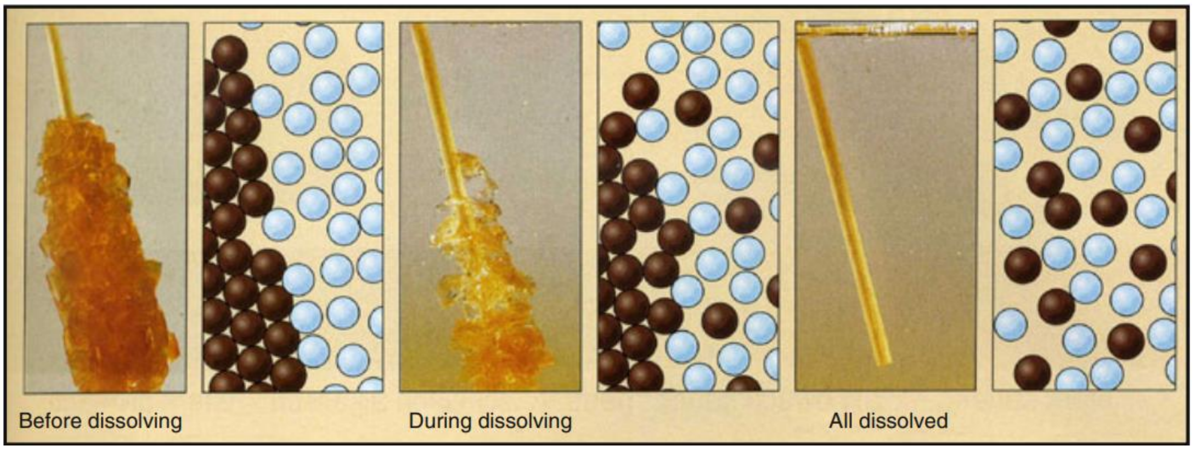

Figure 5. Visualization of Sugar Dissolution in a Solvent (Barke et al., 2012)

In practice, some participants still tend to predominantly use macro-level understanding compared to sub-micro in explaining chemical phenomena at the reaction level (Wang & Lewis, 2020), meaning that participants have difficulty solving problems, especially in the context of reaction mechanisms. Figure 5 describes how sugar dissolution looks in macro and sub-micro terms. In chemistry learning, learning about dissolution tends to be easier for participants to accept logically because it can be seen in real terms. Still, difficulties begin if the sugar dissolution process is discussed at the sub-micro level. This situation shows that the macro and sub-micro worlds are significant in understanding sugar dissolution, as shown in the picture above (Kiernan et al., 2021; Parobek et al., 2021; Schwedler & Kaldewey, 2020; Trivic & Milanovic, 2018; Underwood et al., 2021; Wang & Lewis, 2020). The application of representations in chemistry learning helps participants visualize their mental models even though they are challenging to interpret (Barke et al., 2012; Kapici, 2023; Kiernan et al., 2021; Locatelli & Davidowitz, 2021; Tsaparlis, 2021; Widing et al., 2023).

A simple example of the Stinbuch scheme in science learning is studying the phenomenon of "air pollution." The construction of a molecular model can use an object such as a ball, stick, or chemical molymod. Participants can form the molecular structure of pollutant compounds, namely CO, CO_2, NO_2, and other pollutants. The goal is for participants to easily experience the cognitive transformation of the intended chemical material (concrete model). Next, the teacher can add additional information and explanations relevant to the content being studied through the formation of molecules in the previous stage, including the properties and shapes of molecules (imagination). Next, the teacher enters the sub-microscopic concept, namely studying chemical changes, bond forms, concentrations, and pollutant properties (reality). This stage is referred to in the Steinbuch scheme, which states that the tendency of participants' learning patterns is usually from right to left so that they can easily construct scientific mental models.

In terms of axiology, the modeling scheme in the context of thinking intensely helps someone to believe that particles have value because of their fundamental existence in the universe. The belief that matter is an entity also influences a person's motivation to understand science, considering that the essential nature of atoms is part of a significant change in human life in various fields. Atomic modeling significantly impacts sophisticated products that are currently felt, such as the development of renewable energy, nuclear technology, algorithms in digital platform systems, medicine, artificial intelligence, and simple chemical experiments. The products mentioned go through primary molecular structure modeling stages so that experts have a foundation for developing innovations.

In chemistry education, "thinking in model terms" by Steinbuch (1977) in Barke et al., (2009) is the primary tool that must be used by teachers in training students' thinking skills. Thinking is the most needed activity in the chemistry learning process because the material's content consists of several levels that must be understood. Reinforcing the previous explanation of the context of "air pollution," the level of understanding based on representation is the best vehicle for understanding chemical materials such as macroscopic, sub-microscopic, and symbolic (Barke et al., 2009; Cheng & Gilbert, 2009b). A person's initial knowledge will experience a cognitive transition into scientific understanding if they can think representationally (Parobek et al., 2021; Schwedler & Kaldewey, 2020; Underwood et al., 2021; Widing et al., 2023). Using Steinbuch's scheme, understanding representationally will make it easier for participants to explain chemical phenomena that occur, especially at simple reactions to complex levels (Barke et al., 2009, 2012).

The ability to think at the sub-microscopic level is the most critical part of applying the Steinbuch scheme, considering the importance of realizing that the molecular level is the reality of chemistry. In addition to particulate abilities, the application of the scheme also impacts participants' reasoning and problem-solving skills, so it is hoped that the issue of misconceptions can be reduced gradually (Asmussen et al., 2023; Kranz et al., 2023; Lieber & Graulich, 2020; Rodriguez et al., 2020b; Vo et al., 2022; Wackerly, 2021; Watts et al., 2020). Although everyone has a different pattern of solving problems, the Steinbuch scheme can be a basis for everyone to be able to reason, and problems can be solved at the molecular level. This means that Steinbuch's modeling theory broadly affects human cognitive development. Consistent implementation of the scheme in science learning, including chemistry, can be a bridge of knowledge to achieve quality education in the future.

The study is relevant to various research studies in chemistry education, especially those related to the submicroscopic level. The ability to think at the submicroscopic level is the most essential part of implementing the Steinbuch scheme, considering the importance of realizing that the molecular level is the reality of chemistry. For example, Schwedler & Kaldewey (2020) found that sub-micro skills help strengthen students' conceptual understanding and facilitate the formation of mental models in explaining a context. A scientific mental model makes it easier for students to explain chemical phenomena, especially at the reaction level (Watts et al., 2020). According to Widing et al. (Widing et al., 2023), the submicroscopic approach can help teachers detect the level of student understanding so that teachers can quickly develop chemistry learning relevant to students' cognitive needs. In addition to particular abilities, the application of the scheme also impacts participants' reasoning and problem-solving skills, so it is hoped that misconception issues will be reduced gradually (Asmussen et al., 2023; Kranz et al., 2023; Lieber & Graulich, 2020; Rodriguez et al., 2020a; Vo et al., 2022; Wackerly, 2021; Watts et al., 2020). This means that Steinbuch's modeling theory broadly affects human cognitive development. In terms of implementation, the Steinbuch scheme can improve understanding and the quality of chemistry education, including integration into teaching and curriculum development.

4. Conclusion

A philosophical review of particles as matter is essential to understanding science holistically. The discovery of the Steinbuch scheme confirms that modeling in learning chemistry is essential. The Steinbuch scheme can be a theoretical basis for teachers to quickly explain the essence of learning chemistry. In terms of implementation, Steinbuch's thinking modeling related to "particles" as reality must be accompanied by teachers in the learning context so that students can easily obtain scientific mental structures and models. Another goal is to avoid misunderstandings in interpreting chemical material so that participants' understanding is far from terminology. Using the results of this research makes it easier for participants to explain various phenomena, especially at the molecular level. The research results can also be the primary reference for teachers, researchers, and prospective teachers in designing and developing learning in the classroom. The literacy used is very little, affecting the scope of the discussion explained. They are updating and adding literacy related to quantitative and qualitative issues so that the study can be broader and worthy of being used as a basis for understanding chemistry.

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