

Increasing Students' Conceptual Understanding of Changes in the State of Matter Through the Implementation of Modeling-Based Learning

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Abstract

Abstract

The impetus for this study stemmed from observed stagnation in students' understanding of scientific concepts related to the transformation of matter, with a specific focus on establishing a link between macroscopic phenomena and submicroscopic theories. The objective of this study was to evaluate the effectiveness of implementing Modelling-Based Learning (MBL) in enhancing students' conceptual understanding through an iterative modelling cycle. The present study employed a descriptive qualitative approach, with 54 seventh-grade students at SMP Negeri 2 Wuluhan, Jember, during the 2025/2026 academic year as participants. The primary data were collected by analyzing visual artefacts on Student Worksheets (LKPD), which were then classified using the interactive analysis model proposed by Miles, Huberman, and Saldaña. The findings of the study suggest a progressive dynamic in conceptual understanding: in Stage 1, all students (score 54) were in the non-conceptual category; however, this score increased significantly to 247 conceptual points in Stage 4. Although a "hybrid model" was observed to emerge, characterised by a rise in non-conceptual points in Stage 4 (77 points), the evaluation and revision phase in Stage 5 drastically reduced the number of non-conceptual points to only 9. The findings demonstrate the efficacy of the MBL cycle as a cognitive tool for visualising particulate entities and permanently reducing misconceptions through systematic cognitive restructuring. The study posits that the utilisation of a modelling-based approach has the potential to address the discrepancy between empirical observations and scientific abstractions in science education.

Keywords: Changes in the State of Matter, Conceptual Understanding, Modeling-Based Learning.

Abstrak

Penelitian ini dilatarbelakangi oleh stagnasi pemahaman konsep sains siswa pada materi perubahan wujud zat, khususnya dalam menjembatani fenomena makroskopis dengan teori submikroskopis. Tujuan penelitian ini adalah untuk mengevaluasi efektivitas implementasi *Modeling-Based Learning* (MBL) dalam meningkatkan pemahaman konsep siswa melalui siklus pemodelan yang iteratif. Menggunakan pendekatan kualitatif deskriptif, penelitian ini melibatkan 54 siswa kelas VII di SMP Negeri 2 Wuluhan, Jember, pada tahun ajaran 2025/2026. Data utama dikumpulkan melalui analisis

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artefak gambar pada Lembar Kerja Peserta Didik (LKPD) yang diklasifikasikan menggunakan model analisis interaktif Miles, Huberman, dan Saldaña. Hasil penelitian menunjukkan dinamika perkembangan pemahaman konsep yang progresif, di mana pada Tahap 1 seluruh siswa (skor 54) berada pada kategori non-konsep, namun melonjak signifikan hingga mencapai 247 poin konsep pada Tahap 4. Meskipun sempat muncul "model hibrida" yang ditandai dengan kenaikan poin non-konsep pada Tahap 4 (77 poin), fase evaluasi dan revisi pada Tahap 5 berhasil menekan jumlah non-konsep secara drastis hingga tersisa 9 poin. Temuan ini membuktikan bahwa siklus MBL efektif sebagai alat kognitif untuk memvisualisasikan entitas partikulat dan mereduksi miskonsepsi secara permanen melalui restrukturisasi kognitif yang sistematis. Penelitian ini merekomendasikan penggunaan pendekatan pemodelan untuk menjembatani kesenjangan antara pengamatan empiris dan abstraksi ilmiah dalam pembelajaran IPA.

Kata kunci: Modeling-Based Learning, Pemahaman Konsep, Perubahan Wujud Zat



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1. INTRODUCTION

Contemporary scientific pedagogy has identified science literacy as a fundamental capability imperative for addressing the challenges posed by the ongoing digital transformation (Yunita & Mandasari, 2025). The most recent PISA framework asserts that students' capacity to explain phenomena scientifically extends beyond the mere memorisation of facts. Instead, it requires integrating empirical evidence with logical reasoning (Osborne et al., 2025). However, despite evolving science curricula, students' conceptual understanding in many developing countries remains stagnant, particularly in topics that bridge macroscopic phenomena and microscopic theories.

The subject of changes in the state of matter is a fundamental pillar of the high school chemistry and physics curriculum. The complexity of this material is predicated on the necessity for students to engage in concurrent cognitive activity across three distinct levels of representation: macroscopic (physical phenomena), submicroscopic (particle interactions), and symbolic (formulas/graphs). As indicated by the extant literature, the fundamental cause of persistent misconceptions is the failure to understand particle dynamics at the submicroscopic level (Ulung et al., 2024). Many students hold misconceptions about scientific models, such as erroneous assumptions about changes in particle size during expansion or incorrect suppositions about the apparent disappearance of particles during evaporation. (Saadah et al., 2024). Absent suitable intervention, these misconceptions will hinder the mastery of thermodynamic and energetic concepts at higher levels of education.

Considerable efforts have been made to address these challenges through the utilisation of multimedia and virtual laboratories. Nevertheless, a multitude of studies have indicated that the utilisation of such technologies frequently assumes a "black-box" character. Students are observed to observe simulations without comprehending the mechanisms that underpin them. Consequently, the process of knowledge transfer remains superficial (Wakchaure, 2024). A critical gap in the extant literature concerns students' ability to establish independent connections between empirical observations and theoretical abstractions. The prevailing pedagogical approach in most institutions continues to conceptualise students as recipients of pre-established models rather than as active

contributors to the process of constructing them (Sarıtaş et al., 2021). This underscores the necessity for a more constructivist approach that is oriented towards cognitive processes. These findings are consistent with the results of preliminary observations conducted at several secondary schools in the Jember region of East Java. An analysis of preliminary research diagnostic tests revealed that the majority of students continue to demonstrate an inability to progress beyond the textual-macroscopic level of understanding. In regions characterised by a diversity of learning environments, such as Jember, science education is frequently constrained to the utilisation of textbooks as the exclusive repository of knowledge. This pedagogical approach often results in the cultivation of suboptimal independent representational competencies among students.

Although phase changes can be readily observed in everyday life, for instance, in the processes of boiling water or evaporation, students nevertheless encounter difficulties explaining the fundamental mechanisms underpinning these phenomena. Observations demonstrate that when confronted with boiling water, students can identify macroscopic changes in temperature but fail to represent particle behaviour at the submicroscopic level. A survey of students revealed that more than 60% held the misconception that bubbles in boiling water contain air or heat rather than water vapour. This finding suggests a tendency among students to assume that water vapour has properties entirely different from those of liquid water. This inability to establish a connection between this concrete phenomenon and scientific abstractions suggests that current learning tools are not yet capable of facilitating a deep conceptual visualization. Therefore, an approach is required that can explicitly visualize particle dynamics.

Modelling-Based Learning (MBL) has emerged as a pedagogical approach rooted in the very nature of science itself, namely, the creation of models to explain the universe. MBL employs an iterative modelling cycle in which students construct, test, evaluate, and revise models (Constantinou et al., 2019). From a cognitive perspective, MBL encourages students to externalise their mental models into visual or physical representations that can then be discussed. The process of social negotiation in MBL has been shown to facilitate cognitive conflict, a necessary component for the dismantling of misconceptions and the construction of a more accurate, scientifically grounded conceptual understanding. Through model manipulation, abstract concepts of particle behaviour during phase transitions become more concrete and measurable for students.

The present study aims to evaluate the effectiveness of implementing MBL in improving students' conceptual understanding of changes in the state of matter. The novelty of this study lies in its focus on observing how the modelling cycle can facilitate students' transition from macroscopic thinking to coherent submicroscopic thinking. The results of this study are expected to provide practical contributions to educators in designing instructional plans that visualise the "unseen world" (particles) through systematic modelling activities, thereby effectively bridging the gap between theory and students' actual understanding.

2. METHODS

METHODS

The objective of the present study is twofold. Firstly, an exploration will be conducted into the implementation of Modeling-Based Learning (MBL) and its subsequent impact on students' cognitive processes in relation to understanding complex scientific concepts. To achieve a comprehensive understanding of this phenomenon, this study was conducted using a systematic procedure that included determining the research design, research subjects, and data analysis techniques. The methodology applied in this study is described in detail as follows:

Research Design

The research utilised in the present study is qualitative and employs a descriptive approach. The decision to employ a qualitative approach was predicated on the need to investigate, in depth and in a comprehensive manner, cognitive phenomena and student interactions within a natural learning environment. (Sugiyono, 2019) asserts that qualitative research is a methodological approach grounded in postpositivist philosophy that investigates the natural conditions of the object of study. In this paradigm, the researcher assumes a pivotal role, employing inductive data analysis. The research

outcomes emphasise meaning over statistical generalisations. The design of the study enables researchers to capture the complex reality in the field, particularly in observing how students construct their understanding of abstract scientific concepts through modelling activities.

In practice, the researcher serves as the primary instrument (human instrument), exercising full control over the planning, implementation, data collection, and the holistic analysis and interpretation of research findings. The researcher's involvement in the classroom is not confined to data collection; it also encompasses the roles of participant-observer and facilitator throughout the modelling-based learning (MBL) process. This enables the researcher to maintain a high level of sensitivity to every aspect of learning dynamics, behavioural changes, and the challenges students face as they strive to bridge their understanding from the concrete operational stage to the formal stage.

The present research design focuses on the cognitive transition process of seventh-grade students at SMP Negeri 2 Wuluhan during the odd semester of the 2025/2026 academic year. Utilising a qualitative descriptive approach, the collected data encompasses not only numerical data but also detailed descriptions of student activities, modelling outcomes, and verbal and written expressions that embody their cognitive structures. The primary objective of this design is to provide an accurate picture of the MBL model's effectiveness in facilitating conceptual understanding, so that the researcher can offer meaningful interpretations of the effectiveness of the contextually developed learning tools.

Participants

The research was conducted at SMP Negeri 2 Wuluhan, Jember, with 54 seventh-grade students as research subjects during the odd semester of the 2025/2026 academic year. The subjects were selected using purposive sampling, a technique for determining a sample based on specific considerations relevant to the research objectives. The selection of subjects was based on the necessity to evaluate the effectiveness of the modelling-based learning (MBL) approach in facilitating conceptual understanding among students in the transitional stage of cognitive development from concrete operational to formal (abstract) thinking. Consequently, this group of students was deemed both representative and pertinent as the target demographic for implementing this learning model to assess the extent to which mental models can be optimally constructed.

Instruments

The instruments utilised in this study were meticulously designed to ensure the collection of precise data relevant to the research objectives. The primary tools employed in the learning process comprised science learning modules and Student Worksheets (LKPD), which were systematically organised. These SWLs were specifically designed to document students' visual artefacts at each stage of the MBL model, serving as primary indicators for analysing how implementing this model influences mastery of science concepts, particularly those related to matter and its changes. The utilisation of these artifacts enables the researcher to document, visually and textually, the development of students' mental structures throughout the learning process.

In addition to the learning tools, the researcher also used an observation sheet to monitor the implementation of the Modeling-Based Learning protocol. This was done to ensure that the model was implemented in accordance with the research design. To ascertain students' affective aspects, a questionnaire was administered to evaluate their self-efficacy regarding the completion of assigned science tasks. The collection of data was supported by comprehensive documentation, including photographic, video, and field-note materials. These documents served as both physical evidence and instruments to substantiate the research findings, thereby enhancing the validity of the findings.

Data Analysis

The analysis was conducted using an interactive qualitative approach based on the model of Miles, Huberman, and Saldaña, which comprises four stages. Initially, data reduction was achieved by sorting and simplifying observational data, documentation, and questionnaire responses (Miles et al., 2014). This process was undertaken to focus on mastery of science concepts and self-efficacy. Secondly, the researcher compiled a codebook based on students' drawings in the worksheets to map their level of understanding of the material on substances and their changes. Thirdly, the data were presented as narratives, tables, or diagrams in order to illustrate the patterns of relationships between MBL implementation and student achievement. Finally, conclusions were drawn and continuously verified to ensure the validity of the findings based on strong field evidence.

3. RESULTS

The findings of the subsequent data analysis demonstrate significant shifts in students' conceptual comprehension, characterised by an observable transition in scores from the non-conceptual to the conceptual category at various points throughout the intervention. Preliminary data demonstrate a predominance of non-conceptual responses in Stage 1, which undergo a progressive transformation as the Modelling-Based Learning cycle progresses. The visual representation of the distribution of students' concept and non-concept scores, reflecting the effectiveness of each learning stage, is presented in Figure 1 below.

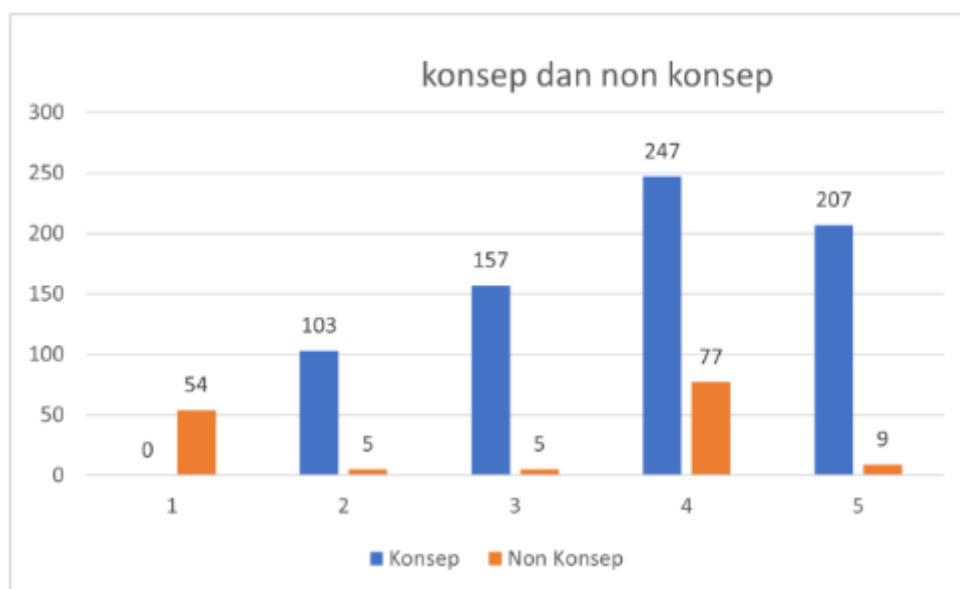


Figure 1. Comparison of the Number of Conceptual and Non-Conceptual Representations by Students at Each Stage of MBL

The findings from the analysis of image representations in the Student Worksheets (LKPD) reveal the dynamics of students' conceptual mastery, distributed across the five stages of Modelling-Based Learning (MBL). In Phase 1, the findings of the identification process showed that no representation belonged to the concept category. Consequently, the cumulative score was exclusively in the non-concept category at 54 points. As the second stage was initiated, quantifiable metrics about the concepts began to manifest, amassing a total of 103 points. This trend persisted into the subsequent third stage, during which the indicators rose to a maximum of 157 points. The most significant surge occurred in Stage 4, where students' concept mastery reached the highest figure of 247 points during the study; however, at the same stage, a sharp fluctuation was also recorded, with a significant increase in non-concept points to 77 points. This data dynamic then stabilised in Phase 5, where, although the concept score was adjusted to 207 points, the non-concept category underwent a drastic decrease, leaving only 9 points remaining. The analysis of these data indicates that throughout the MBL cycle, there was a shift in the distribution of points from one initially dominated by the non-concept category at the start of the learning process to one dominated by the concept category, with a very low residual non-concept score at the end of the phase, as systematically recorded in the comparison graph in Figure 1.

In addition to the dynamics of conceptual mastery, field observations also captured students' psychomotor and affective responses as they interacted with the Modeling-Based Learning (MBL) instrument. In the preliminary stage, students frequently showed reluctance to begin drawing on the worksheets. The majority of students appeared to anticipate comprehensive verbal instructions, as they were habituated to expository methods. However, a marked intensification of classroom activity was observed upon entering the model-construction stage, a students transitioned from passive to more

active and self-directed in their exploration. A profound internal cognitive process was evident as students endeavoured to translate abstract concepts into visual symbols on their worksheets. However, in the subsequent stage, a challenge emerged: several students found it difficult to manage their time effectively between the independent reasoning phase and the completion of detailed drawings on the worksheets. This ultimately resulted in incomplete or rushed representations.

The classroom environment incorporates experiential learning exercises that illustrate how ice (a solid) transforms into a liquid when heated. In this setting, the instructor's guidance is instrumental in prompting student thinking (rather than furnishing immediate answers). It plays a pivotal role in minimising the proportion of students encountering challenges in grasping the concept. When confronted with the phenomena of matter and its submicroscopic changes, students have a natural tendency to utilise analogies from everyday life that are not always scientifically accurate. However, as the iterative cycle progresses, changes are observed in how students approach their models; they no longer view the diagrams as an administrative task, but as a tool to validate their own reasoning. The critical reflections that emerged spontaneously at the conclusion of the session indicate that independently revising models in the field is significantly more effective than one-way corrections from the teacher. This finding is directly correlated with a substantial reduction in non-conceptual points in the final stage of the study.

4. DISCUSSION

The dynamics of students' conceptual understanding, as observed throughout the implementation of Modelling-Based Learning (MBL), indicate a highly progressive cognitive transformation, characterised by the modelling of abstract concepts and their subsequent application to real-world situations. Findings from the initial stages suggest that students were initially unable to move beyond an intuitive, macroscopic understanding. This suggests the existence of a 'representation gap' typically encountered in the subject matter and its changes, whereby students were unable to visualise particulate entities independently. However, a significant cognitive shift occurred as the model-construction phase began. Model-construction activities effectively triggered the externalisation of students' scientific ideas from abstract forms into visual representations. This phenomenon aligns with Ainsworth & Scheiter (2020) view that student engagement in constructing representative images enables deeper submicroscopic reasoning than passively receiving verbal explanations.

Furthermore, these findings reinforce the study by Gilbert and Justi (2016), which asserts that modelling activities are a thinking process in which students construct mental models to explain the mechanisms behind observed phenomena, rather than merely visual aids. The research by Tytler et al., (2020) also supports students' ability to transform abstract concepts into visual representations, revealing that active engagement in creating representations (such as particulate images) is key to understanding the relationship between the macroscopic and abstract submicroscopic levels. Thus, externalising ideas enhances conceptual mastery and builds students' visual literacy in communicating complex scientific phenomena.

Students' integration of scientific symbols into cognitive structures demonstrates MBL's function as a powerful cognitive tool. As Avargil & Saxena (2023) emphasise, visual modelling activities effectively help students overcome barriers to understanding the particulate nature of matter, which is often considered too abstract at the elementary and secondary education levels. This finding is also consistent with Wang et al., (2024) argument that using dual representations (visual and symbolic) is crucial in helping students to construct a coherent knowledge structure regarding invisible phenomena. However, an anomaly has emerged: a rise in non-conceptual scores at the very peak of conceptual achievement (Stage 4), an intriguing finding. Qualitatively, this phenomenon reflects a complex phase of cognitive restructuring: students begin to attempt to integrate new, more abstract concepts, thereby triggering the emergence of a 'hybrid model'. This can be explained by Nielsen & Nielsen (2021) perspective on modelling competence, whereby the overlap between intuitive knowledge (p-prims) and newly acquired formal knowledge often triggers cognitive uncertainty.

Ross & Andreas (2024) also reported this tendency towards the emergence of temporary misconceptions or hybrid models, noting that students often engage in 'misgeneralisation' when transitioning from simple to more complex models before eventually reaching a stable understanding. Furthermore, Göhner & Bielik (2022) caution that modelling-based instruction can cause cognitive overload if students are asked to integrate too many variables at once. This is reinforced by Munshi et al, (2023) study, which shows that students' inability to connect various levels of representation simultaneously often triggers temporary confusion during the transition phase. In this study, this confusion was clearly evident in the fluctuations in the data during Stage 4.

The success of this intervention was ultimately validated in the final stage through a process of conceptual refinement, whereby the number of non-concepts was minimised. This demonstrates that the iterative cycle in MBL enables residual elements of the hybrid model to be 'cleansed' through independent model evaluation and revision. This finding is strongly supported by Schwarz & Manz (2022), who emphasise that modelling's primary strength lies not in creating the initial model, but in students' ability to revise it based on new evidence. Consistent with this, Jaiswal et al, (2021) research confirms that the reflective cycle in modelling is highly effective in uncovering hidden misconceptions and facilitating students' independent improvement in understanding.

Consequently, fluctuations during the learning process are not indicative of failure but rather of a dynamic conceptual shift. Zuccarini & Malgieri (2024), theory of Conceptual Change is supported by this phenomenon, which states that a phase of inconsistency is often experienced before a more stable cognitive structure is eventually reached during cognitive transitions toward scientific understanding. These results reinforce the idea that science education should prioritise a multi-representational approach to effectively and permanently bridge the gap between macroscopic understanding and submicroscopic reality. Haque (2024), supports this in the Multi-Representational Framework, stating that the integrated use of various representations aids understanding and limits misinterpretations. This makes the formed concepts more meaningful and enduring in students' long-term memory.

5. CONCLUSION

Implementing Modelling-Based Learning (MBL) has been shown to significantly improve students' conceptual understanding of changes in the state of matter through a series of systematic modelling cycles. This study reveals that externalising ideas through visual representations on worksheets successfully bridges the gap between macroscopic observations and submicroscopic reality, enabling students to grasp particle dynamics more concretely. Although cognitive fluctuations that gave rise to a 'hybrid model' occurred during the middle phase, the iterative process of evaluating and revising models proved effective in refining students' understanding and drastically reducing misconceptions by the final stage of learning. Thus, the MBL approach is a cognitive tool that facilitates the transition from intuitive to coherent and enduring scientific thinking.

Author Contributions:

Conceptualization, Ike Rusdiana and Rayendra Wahyu Bachtiar; Methodology, Ike Rusdiana, Rayendra Wahyu Bachtiar, and Sulifah Apriliya Hariani; Validation, Rayendra Wahyu Bachtiar and Sulifah Apriliya Hariani; Formal Analysis, Ike Rusdiana and Rayendra Wahyu Bachtiar; Investigation, Ike Rusdiana; Resources, Ike Rusdiana and Sulifah Apriliya Hariani; Data Curation, Ike Rusdiana and Sulifah Apriliya Hariani; Writing—Original Draft Preparation, Ike Rusdiana; Writing—Review & Editing, Rayendra Wahyu Bachtiar and Sulifah Apriliya Hariani; Visualization, Ike Rusdiana and Rayendra Wahyu Bachtiar; Supervision, Rayendra Wahyu Bachtiar; Project Administration, Ike Rusdiana; Funding Acquisition, Ike Rusdiana. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest:

The authors declare no conflict of interest. The authors have no financial, professional, or personal relationships that could be perceived as influencing the research, analysis, interpretation of data, or the publication of the results reported in this manuscript.

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