https://doi.org/10.24036/jep/vol9-iss1/1000

JEP (Jurnal Eksakta Pendidikan)
Volume 9, Issue 1, 81 – 96
ISSN: 2579-860X (Online), ISSN: 2514-1221 (Print)
https://jep.ppj.unp.ac.id/index.php/jep

Mental Model in Physics Learning: A Systematic Literature Review

Isnaini Agus Setiono*, Lasiani, Mustika Wati, Dewi Dewantara
Physics Education Study Program, Faculty of Teacher Training and Education, Universitas Lambung Mangkurat, Banjarmasin, Indonesia

Received: April 4th, 2025 ▪ Revised: May 5th, 2025 ▪ Accepted: May 15th, 2025

ABSTRACT

A mental model plays an important role in students' understanding of physics concepts. However, proper physics learning is challenging in facilitating students to construct scientific mental models. This study aims to systematically investigate physics learning strategies that effectively support the construction of students' scientific mental models. A systematic literature review was conducted using the Scopus database on 234 articles from 2015-2024, then systematically selected 15 articles that are relevant to the topic. This study reveals that using various visual media in physics learning can build students' mental models. This is because visual media representation helps facilitate the modelling of physics concepts in the minds of students. Mechanics, electronics, temperature and heat, and modern physics are the physics learning topics with the most potential for constructing students' mental models. This research finds that previous studies are not directly related to each other, such as mental models, visual representations, and real-world life, especially at the high school level. This is a potential opportunity to be explored further in further research. The findings of this study present evidence-based recommendations to contribute significantly to the implementation of effective physics learning innovations to build students' scientific mental models.

Keyword: Conception, Mental Model, Physics Learning, Systematic Literature Review

INTRODUCTION

A mental model is a picture of a person's thinking in accessing knowledge patterns that are useful for solving problems (Corpuz & Rebello, 2011), constructing explanations for the phenomena faced, and understanding and explaining situations reasonably (Basori et al., 2020). The term mental model consists of three components: a pattern of visual modality, functionality, and individual aspect (Ubben & Bitzenbauer, 2022). The mental model is one of the things that has a crucial role that must be built by every student. This is because a good mental model encourages students to construct scientific conceptions. The mental modelling process in physics learning can be used to investigate physics concepts (Batlolona & Diantoro, 2023). Mental models in physics learning also indicate that there is a good reason to build

***Correspondence:**
Isnaini Agus Setiono, Physics Education Study Program, Faculty of Teacher Training and Education, Universitas Lambung Mangkurat, Banjarmasin, Indonesia.
✉ email: isnainiagussetiono@ulm.ac.id

knowledge through clear statements of the allegations of the phenomenon. Teachers can access information to help students build their conceptual understanding (Hurtado-Bermúdez & Romero-Abrio, 2023). The term "mental model" or "representation" is often used in research related to misconceptions in science education (Ravanis, 2019). This term refers to the internal representation of an object, process, or how this analogous structure or process works (Mansyur et al., 2022). Students often test their mental model abilities when faced with new situations. It involves many representations, rules, and steps at each development point, challenging learners to apply. Thus, learners can construct and change their mental models during the learning activity. This is in accordance with the theory of constructivism, which states that learners can build their own knowledge. In this process, learners can build conceptions through the process of assimilation and accommodation (Cakir, 2008; Posner et al., 1982). The ability of learners to change their conceptions depends on the flexibility of their internal representations (Mansyur et al., 2022).

Mental models are one of the interesting cognitive science research topics in psychology and science education (Corpuz & Rebello, 2011). This field of research is an attraction for researchers to further analyze students' mental models in physical systems, including phenomena at the macroscopic and microscopic levels (Mansyur et al., 2022). Several studies on students' mental models have been conducted previously, such as the analysis of the characteristics of students' mental models (Amiruddin et al., 2025; Mansyur et al., 2022) and learning strategies that can build students' mental models (Hamrick et al., 2016; Mansyur et al., 2020). In addition, several previous studies have been conducted related to mental models in macroscopic and microscopic phenomena, such as those conducted by Nongkhunsarn et al., (2019), Mansyur et al., (2022), Yusof & Arshad (2022), and Batlolona & Jamaludin (2024). However, a comprehensive analysis of learning that is genuinely effective in encouraging the formation of students' mental models needs to be carried out.

The novelty of this study lies in the comprehensive approach to evaluating physics learning that can build students' scientific mental models through meta-analysis. This study examines and explores holistically physics learning, such as the models, approaches, and learning methods used, the learning media used, the level of education, and the relevant learning topics. A holistic analysis of the relevant empirical research evidence provides new insights into physics learning innovations that are considered more effective in building students' mental models. These learning innovations include learning design, learning media used, and learning assessment designs that support the construction of students' scientific mental models. This synthesis evaluates the effectiveness of physics learning in several studies and identifies its characteristics. Furthermore, the advantages of this learning can contribute maximally to improving physics learning practices and the making of various policies by policymakers related to this.

This study aims to analyze physics learning that can facilitate the construction of students' scientific mental models. The analysis is based on previous studies. The specific objectives are to analyze physics learning that can construct students' mental models, identify topics in physics learning that have the potential to build students' mental models and find out the opportunities for research topics that have the potential to be developed related to mental models.

METHOD

Research Design

This research was conducted using the Systematic Literature Review method. Data was systematically analyzed on several journal articles related to the research questions. This Systematic Literature Review research was conducted by analyzing the data obtained based on the research questions. These research questions are stated:

RQ1. How do physics learning activities construct students' mental models?

RQ2. What physics learning topics related to mechanics, temperature and heat, and electromagnetism have the potential to construct students' mental models?

RQ3. Are there potential research topics related to mental models that need further research or development?

Meta-analysis and systematic review in this study adopted the steps of (Hansen et al., 2022). The PRISMA guideline is used in presenting items for the meta-analysis and systematic review stages so that all stages of the review run clearly and systematically (Arifin et al., 2025; Moher et al., 2009; Wei et al., 2024). Several stages of PRISMA analysis can be visualized and observed through the research stage flow diagram in Figure 1.

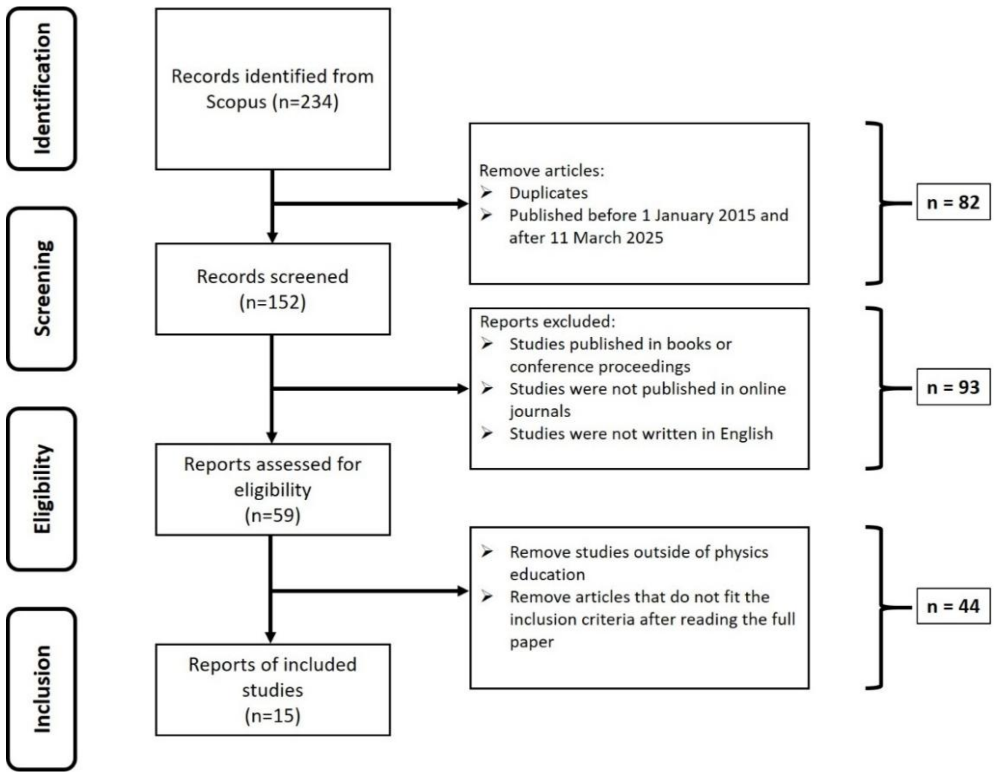


Figure 1. Flowchart of PRISMA stages (Source: Authors' elaboration)

The research stages were carried out systematically, from planning to reporting the results (Geng & Su, 2024). Research questions were formulated, and inclusion and exclusion criteria were determined based on the research focus (Ting et al., 2023). In the selection process, the title and abstract were analyzed to determine whether they were in accordance with the research criteria (Zawacki-Richter et al., 2020). Thus, several articles that met these criteria were obtained and selected. Data from the selected articles were then compiled and further analyzed.

Instruments

The articles analyzed were from the Scopus database from 2015 to 2024. The Scopus database was used because this study was conducted to analyze research data with a broader scope. The specific search in Scopus used in this study was TITLE-ABS-KEY (model AND mental AND physics AND education OR learning OR teaching), which was done manually. Data in CSV and RIS formats were analyzed using Microsoft Excel, Zotero, and VOSViewer. Microsoft Excel and Zotero were used to analyze data duplication and metadata. Meanwhile, visual analysis was carried out using VOSViewer. VOSViewer is used in network analysis, which shows the relationship between publications, journals, researchers, or keywords (Sahrir et al., 2024). Edges not only indicate the relationship between two terms but also the strength of the relationship, which is indicated by the distance. The closer the distance between one term and another, the stronger the relationship between the two terms.

Data Analysis

Data was analyzed using Microsoft Excel, Zotero, and VOSViewer programs. Data obtained from Scopus were then cleaned and arranged through a selection process of titles, abstracts, and keywords by entering search keywords. An initial search of 234 data was obtained. The publications analyzed were in the range of 2015-2024. The selection was based on covering data over a long period so that it could describe changes in research related to the topic (Smela et al., 2023). The data selected were only in the form of journal articles, not including proceedings and books. The review was carried out only on articles in English to meet the inclusion criteria and provide accurate interpretation results. The review includes publications from various countries, which have explored the research topic in more depth (Kolaski et al., 2023). The inclusion and exclusion criteria in this study can be stated in Table 1.

Table 1. Criteria of Inclusion and Exclusion

Criteria	**Inclusion**	**Exclusion**
Type of publication		
Journal articles	√	
Conference papers		√
Reports		√
Dissertations		√
Books and book chapters		√
Publication period		
January 2015-March 2025	√	
Language		
English	√	
Other		√
Place of study		
Worldwide	√	
Type of study		
Empirical investigation	√	
Literature reviews		√
Theoretical reviews		√

Visual analysis of the data was performed using VOSViewer. At this stage, three types of visualizations were produced, namely network analysis, overlay, and density. Network visualization illustrates the relationship between keywords. Overlay visualization shows the mapping of keywords in each year. Meanwhile, density visualization provides an overview of how many keywords appear. This study focuses on the results of network visualization to answer research questions. The last stage in this study is the interpretation of research findings.

RESULTS AND DISCUSSION

Results

A systematic review using proper research principles was conducted, and the researcher obtained 234 articles on related topics from the Scopus database. The articles were selected based on the title, keywords, duplicate articles, and year of publication. A total of 82 articles were removed from the selected article group. The researcher re-selected the articles based on the type of article, the place of publication, and the language used in writing the article. 59 articles were obtained based on the selection results according to these criteria. Furthermore, the researcher selected articles based on the field of study and the content after thoroughly reading the abstracts and contents of the articles. A total of 44 articles did not meet these criteria. Thus, 15 articles were obtained that met the criteria for the study. The final selected articles provide physics learning that can shape students' mental models.

The development of research on mental models in physics learning is shown by the number of articles published every time. Thus, it can be said that there is no limit to the selected research articles. However, this study emphasizes reviewing the latest research results conducted related to students' mental models in physics learning. To meet this goal, research articles collected from the Scopus database are from 2015 to mid-March 2025. As shown in Figure 2, the majority of articles were published between 1981 and 2025. This means that a large wave of physics learning is oriented towards constructing students' mental models.

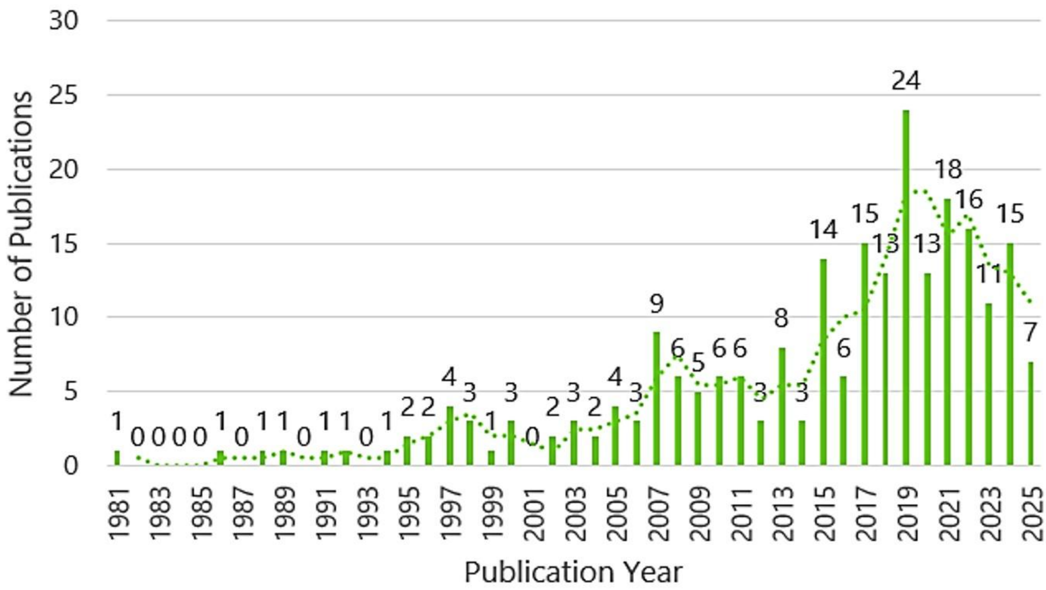


Figure 2. Number of mental model publications each year

The number of studies on this topic in Figure 2 appears to be increasing, with the most significant increase occurring in 2019. There were 24 research articles published on this topic. Figure 2 shows that there was a significant increase in the number of publications in 2019, which marks an increase in researchers' interest in the topic of mental models in physics learning.

Publication type is a type of place to publish articles, namely journals, seminars, conferences, reviews, books, and others. This place, whether journals or publishers, implements peer-reviewed and meets the academic publication work system. The types of research publications related to mental models are shown in Figure 3.

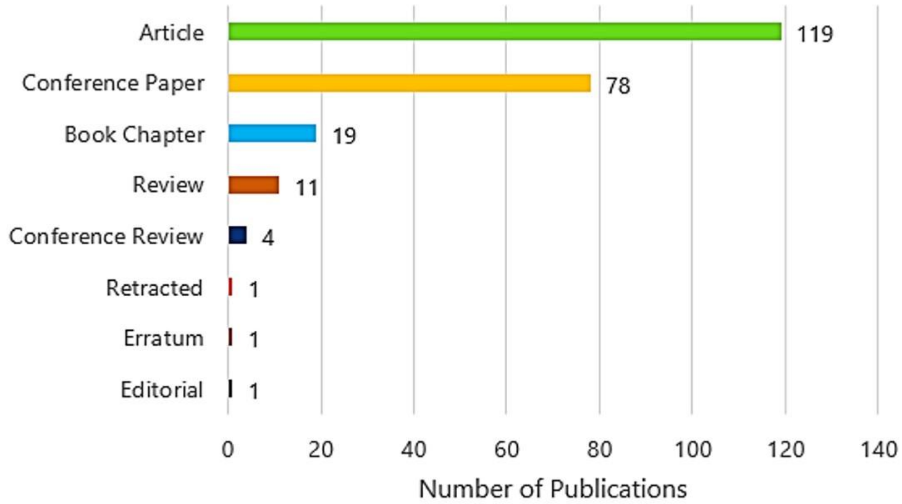


Figure 3. Sources of mental model publications

According to Figure 3, the distribution of articles shows that 51% (119 articles) are in journals. Articles published through conference papers reach 33% (78 articles). In addition, articles are published in book chapters, reviews, and conference reviews.

Research articles on mental models that have been published come from researchers in various countries. Figure 4 shows the top 10 countries that publish the most mental model articles in Scopus-indexed journals. In accordance with Figure 4, the United States ranks at the top in publications on this topic. As many as 30% (71 articles) have been published by researchers from the United States. Meanwhile, Indonesia ranks second in publications on this topic. Researchers from Indonesia have published as many as 11% (25 articles) on this topic.

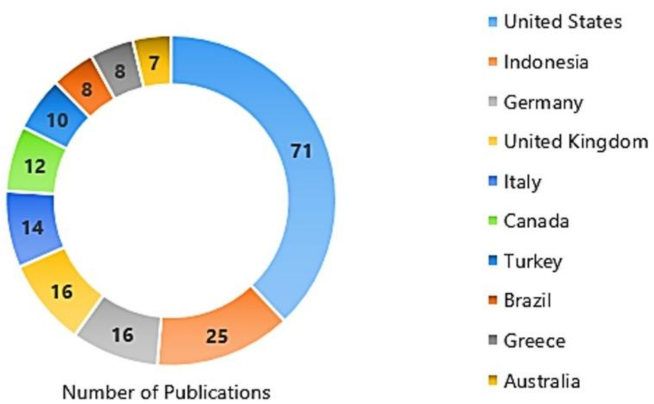


Figure 4. Number of mental model publications per country

Computational visualization analysis using VOSviewer has been carried out holistically. This visualization was carried out to map research trends on mental models in the last 10 years. Figure 5 shows a network visualization on this topic. The relationships between concepts are presented in various colors. Concepts with the same color have the same cluster (Nandiyanto et al., 2021; Nandiyanto & Al Husaeni, 2021; Nurmahasih & Jumadi, 2023).

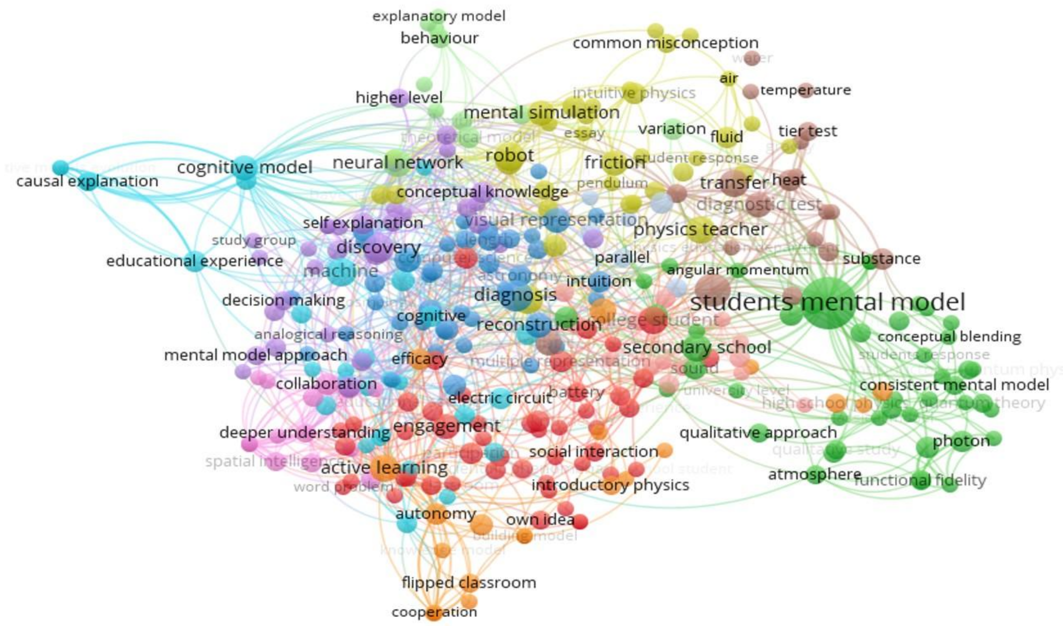
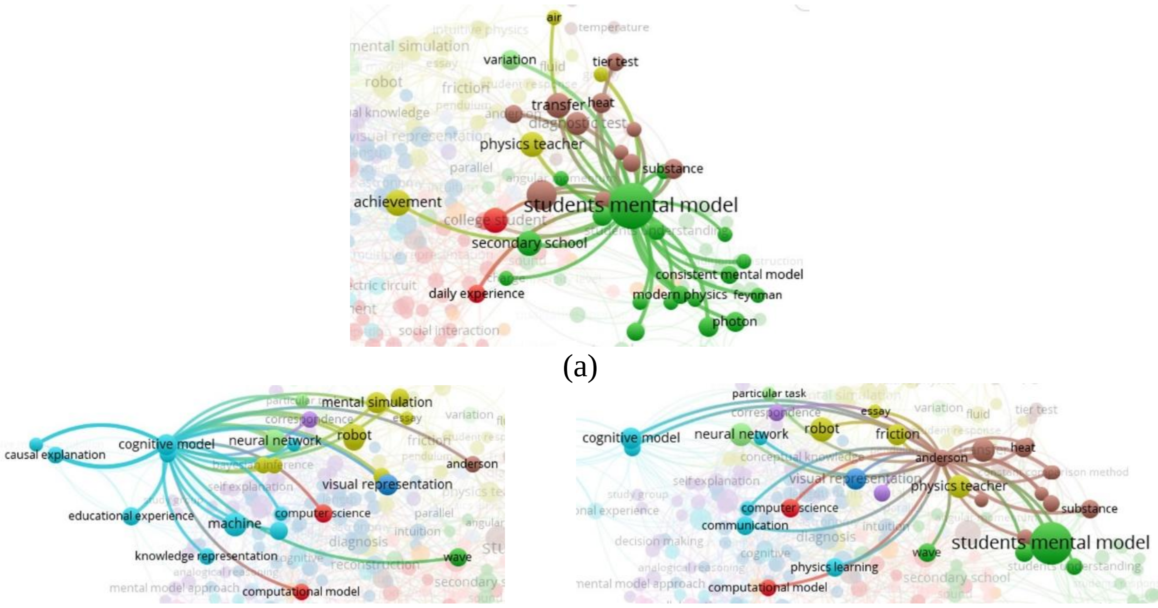


Figure 5. Network Visualization Related to Mental Models

Network visualization according to Figure 5 has mapped the relationship between several diverse concepts in the field of education, where the "student mental model" is the center of this network. Several concepts are connected to this center point, such as "visual representation", "cognitive model", "Anderson", and so on. This gives meaning to the importance of mental models in education. In network visualization, the closer the relationship between concepts is marked, the denser the network relationship (Amiruddin et al., 2025). This also gives meaning to an approach to understanding and developing educational practices holistically. For an educator or researcher in the field of education, this network visualization can be helpful for seeing the differences in the relationship between educational theory and practices that have been carried out in the field. Thus, a stakeholder can conduct an in-depth analysis of the area of authority in order to make decisions and collaborate concerning the field of education, especially physics education. Furthermore, educational outcomes can be improved. According to Figure 6, the presence of concepts such as "flipped classroom", "computer science", and "computational model" indicates that it is essential to integrate technology in forming students' mental models.



(a)

(b) (c)

Figure 6. Visualization of the Relationship Between (a) Mental Models, (b) Visual Representations, and (c) Cognitive Models

This network visualization analysis results provide a bright picture of the current educational research trends. In addition, it helps us identify very potential research gaps and have the opportunity to be developed further.

Discussion

In this section, the research questions that have been described in the method section are discussed by referring to the articles that have been obtained based on the results of the selection that has been carried out. In addition, this section identifies physics learning in the construction of students' mental models. Furthermore, this section also allows further researchers to find potential research topics related to mental models and opportunities for further development.

Physics Learning That Can Construct Students' Mental Models

Many studies have examined the role of technology in physics learning. However, only a few have examined its effects on the formation of students' mental models directly. This study fills this gap by providing a more comprehensive picture of the application of various types of technology in physics learning at the university level. At the college level, physics courses to construct mental models can be done using textbooks that directly present macroscopic and microscopic phenomena (Altan Kurnaz & Eksi, 2015). This phenomenon is expressed in image visualization accompanied by explanations in text mode. Visualization is done both in teaching materials and assessments. Thus, teachers can analyze students' mental models through the results of their work. The results of previous studies state that flipped classrooms combined with active learning and traditional learning are pedagogical strategies that can encourage students to build and construct their mental models of knowledge (Sánchez-Azqueta et al., 2019). In this learning, two resources are needed, namely learning support materials and learning assessment materials and model construction. Learning support materials can be webinars, applets, tutorials and lectures, simulation tools, virtual laboratories, and problem-based learning (PBL) sessions. Meanwhile, learning support materials and learning assessment materials can include quizzes, problems, reports, and wikis. In line with previous studies, the PBL model can improve students' mental models (Batlolona & Souisa, 2020). In this learning, image representation, contextual concept analogies, and the PhET virtual laboratory mode also improved students' mental models.

Technology-based physics learning in higher education is still a powerful solution for building students' mental models. In addition, using various visualizations in learning, such as graphic visualization, 3D objects, computer programming using Python language, and Python-based virtual laboratories, encourage students to understand physics phenomena better and form appropriate mental models (Bufasi & Lakrad, 2019). One of the uses of these various visualizations is that they cannot only present macroscopic concepts in real terms but various microscopic physics concepts can also be presented to students. In line with previous research, using PCs and interactive multimedia boards in the classroom encourages students to build mental models more easily (Malgieri et al., 2017). This multimedia board allows the class to be connected to the internet, with access to videos, PASCO virtual laboratories, GeoGebra simulations, Data studio programs, and Microsoft Excel. Physics learning by utilizing games (such as Mario) can effectively improve students' conceptual understanding (Anupam et al., 2018). This is because games can encourage students to build a learning environment that motivates them to learn. In addition to games, artificial intelligence (AI) and augmented reality (AR) technology in learning promise a revolution in teaching and learning methods. Integrating AI and AR in learning provides an impressive learning experience for students so that students' conceptual understanding and mastery of concepts can increase (Zouhri & Mallahi, 2024). Through this AR, visualization and simulation of physics concepts can be presented in class comprehensively. This has the potential to encourage students to play spatial intelligence well, which plays an important role in helping students to represent objects and equations and form their mental models. Meanwhile, AI can analyze AR-generated data. Thus, collaboration between teachers, students, and technology is important.

The presence of various media, such as visual media and laboratories, does not leave out the interaction activities between students in learning activities. Previous studies have revealed that learning that allows students to interact with each other in the classroom provides benefits in the construction of scientific mental models (Körhasan, 2021). This learning can be done using the Peer Instruction (PI) method, which is combined with collaborative learning based on interactive projects and group discussions. In this learning, all activities in class, assessments, and projects are carried out in groups, where this group is determined by the teacher. Students carry out activities reading textbooks related to the concepts to be studied. This is intended so students have the knowledge to carry out the group discussion phase. Not only that, students also underline important concepts and provide notes on the text. Students are given specific questions about concepts that are not yet understood. These questions can be accessed by other students. In line with previous studies, learning that focuses on the teacher and is not accompanied by the use of analogy techniques, asking questions, and discussions does not encourage students to form their mental models (Ozcan, 2017).

Physics learning at the high school level through the problem-based learning (PBL) model is more able to help students construct their mental models compared to conventional learning (Batlolona et al., 2020; Batlolona & Diantoro, 2023). The study's results also revealed no direct relationship between mental models and students' creative thinking skills, either in learning with the PBL or conventional models (Batlolona & Diantoro, 2023). When compared to conventional learning models, the PBL model is effective in forming students' mental models on the topic of solid and elastic objects (Batlolona et al., 2020). Various modes of representation, such as text and image visualization in the assessment instrument, also have an impact on the construction of students' mental models.

In addition to the use of various modes of representation, the strategies used in learning also have an impact on the construction of students' mental models. Modeling is one of the learning strategies that can shape students' mental models (Sands, 2021; Wade-Jaimes et al., 2018). Through this strategy, students carry out learning activities with metacognitive tools in various models, such as physical and mathematical simulations. Modeling is carried out by students on the phenomena given by the teacher. Thus, this will make students remember the concepts learned better so that meaningful conceptual changes can occur. In the discussion and questioning sessions in this learning, several activities are carried out, namely, initial probe, physical exploration, analogy, simulation, and mathematical modeling. Modeling can encourage students to make sense of the problem, be consistent with mathematical implications with known facts, and connect the model to everyday life (Sands, 2021). Furthermore, the first stage in constructing students' mental models is building a mathematical model to solve problems. In modeling learning, students learn by using learning media to describe the model. Learning media can also be used to diagnose students' mental models, one of which is Newton's cradle tool (Sarapak & Kearns, 2022). Furthermore, the interactions that occur during learning activities affect the process of constructing students' mental models (Körhasan et al., 2015). Studies have shown that students' mental models are influenced by teaching styles, such as learning methodologies and specific techniques teachers use to teach learning material content. In addition, the sequence of learning topics, concepts that students often encounter, and peers also influence this.

Physics Learning Topics That Can Construct Students' Mental Models

After conducting systematic review research and mapping, several physics learning topics were obtained that could potentially construct students' mental models. Solid friction is a physics learning topic that can construct students' mental models in grade nine (Kurnaz & Eksi, 2015). In this topic, students' mental models are well formed in macroscopic concepts, but students have difficulty in microscopic concepts. Furthermore, students' mental models related to microscopic concepts are included in the unscientific category. Thus, educators need to explain the concept of solid friction well at the macroscopic, mesoscopic, and microscopic levels. In line with the previous topic, solid elasticity is a topic that has the potential to construct mental models of high school students (Batlolona et al., 2020; Batlolona & Diantoro, 2023). This topic includes elastic and plastic objects, strain, stress, Young's modulus, and Hooke's law related to both series and parallel spring arrangements. On the topic of elastic and plastic objects and series and parallel spring arrangements, the achievement of students' mental models is good (Batlolona et al., 2020). However, on the topic of Hooke's law, there is only a minor achievement of students' mental models. This student mental model does not directly relate to students' creative thinking skills (Batlolona & Diantoro, 2023). Mechanics topics, such as Newton's third law and buoyancy, can construct students' mental models (Sands, 2021).

In addition to the mechanics topic, students can construct their mental models through physics learning on topics related to temperature and heat, mechanics, and electronics. High school students' mental models can improve through physics learning related to the topic of temperature and heat, especially on the concept of water conductivity (Batlolona & Souisa, 2020). In this topic, students' mental models increase with high early capability. In addition, there is an increase in low-skilled student mental models on this topic. The topic of electricity allows high school students to construct mental models (Wade-Jaimes et al., 2016). This topic includes static electricity, current electricity, the relationship between current, potential difference, and resistance (Ohm's law). In line with this topic, students' mental models have the potential to be formed through physics learning on the topic of discharge of a capacitor through a series of resistors and case hardening of steel by high-power laser diodes (Sands, 2021). Unlike previously explained topics, mechanics topics such as momentum and the principle of energy conservation provide opportunities for students to form their mental models (Sarapak & Kearns, 2022). However, students need to comprehensively understand this concept in order to develop the ability to apply the concept. Physics topics related to the function of physics modeling have the potential to facilitate the formation of students' mental models (Zouhri & El Mallahi, 2023). These topics can stimulate students to play spatial intelligence, encouraging them to form mental models.

At the level of students in college who take physics or relevant courses, electronics topics are topics that have the potential to form students' mental models (Sanchez-Azqueta et al., 2019). Examples of these topics are microelectric circuit transistors, CMOS technology, thermal equilibrium, and semiconductors. These topics are able to encourage students to construct mental models. In addition, this topic allows them to connect and check models. In virtual laboratory-based learning, the topics of essential atomic physics and nuclear physics, both electric and magnetic fields, have the potential to construct students' mental models (Bufasi & Lakrad, 2019). Meanwhile, in undergraduate-level physics courses related to the topic of wave-particle duality, students' mental models tend to increase (Korhasan, 2021). In addition, students can achieve a scientific model, which is marked by their satisfaction with their knowledge. In line with the topic, quantum physics, wave-particle duality, and the uncertainty principle can also potentially construct students' mental models (Malgieri et al., 2017). Students' mental models on this topic increase consistently, in detail, and integrated mental models, especially the view of photons and electrons. However, the topic of the uncertainty principle is less clear-cut. Blackbody radiation, the photoelectric effect, and the Compton effect are topics that students can learn to form their mental models (Ozcan, 2015). In this topic, students are able to accelerate the formation of hybrid models and beam-ray mental models. Meanwhile, the particle model type mental model is less accelerated by students. Furthermore, quantum mechanics topics, such as the relationship between wave functions, the chance of finding electrons in a specific place, and changes in wave functions during changes in energy levels, can train students to construct their mental models (Anupam et al., 2017). On this topic, students' conceptual understanding increases. Learning topics related to modern physics, such as quantum theory, both quantum physics and quantum mechanics, are able to facilitate the construction of students' mental models (Korhasan, Eryilmaz, & Erkoc, 2015).

Potential Research Topics for Further Research or Further Development

Based on network visualization, keywords have a close relationship with the relevance of thematic development. This is evidenced by the emergence of similar keywords, such as "student mental models," "visual representation," and "cognitive models." Trend keywords are one of the valuable things because they can explain the contents of the article. Keywords are always used in an article (Agarwal et al., 2016; Amiruddin et al., 2025). Many previous studies use keywords to capture research trends (Nurmahasih & Jumadi, 2023; Prahani et al. pdf_240518, 2024; Ahel et al. document (1), 2025). Research topics related to mental models that have the potential to be developed further according to Figure 5 include the development of misconception diagnostic tests, computer-based learning designs for conceptual reconstruction, and the development of learning based on a mental model approach that is oriented towards mental model consistency. Research can also examine how visual representation modes can affect students' cognitive models, the effect of spatial intelligence on the consistency of students' mental models, technology integration, such as computer simulations in learning that are oriented towards decision-making skills, and qualitative analysis of the effect of analogical reasoning on the construction and consistency of students' mental models. In addition, studies on developing flipped-classroom-based learning can increase teacher effectiveness in reconstructing students' misconceptions. The results of the network visualization shown by VOSviewer explain the relationship between keywords and the relationship between clusters (Kumar et al., 2014; Yang & Thoo, 2023). Furthermore, some keywords will look familiar or unfamiliar based on the cluster's size or the cluster's brightness and lack of brightness. This network visualization is used as a way to find research findings and novelty from a study (Oyewola & Dada, 2022).

The results of this study also show that in 2019, many researchers published articles related to mental models. This is because in 2019, there was a COVID-19 pandemic, so physics learning was done online (Marzoli et al., 2021). This learning has an impact on low conceptual understanding because there is learning loss, which affects students' mental models (Engzell et al., 2021; Kuhfeld et al., 2020). Therefore, many studies related to mental models have been conducted this year. This study is limited to the analysis of articles published by Scopus, so further research is needed to analyze articles other than those published by Scopus. Further analysis of publications other than Scopus is needed to analyze more comprehensively the research related to students' mental models in physics learning.

CONCLUSION

Based on the results of this systematic literature review study, it was found that physics learning activities using a variety of visual visualizations integrated with technology can support the construction of students' mental models. Physics learning topics that have the potential to build students' mental models are related to solid friction, solid elasticity, mechanics, electronics, temperature and heat, quantum mechanics, and modern physics. The reality gap between students' mental models, visual representations, and experiences in everyday life is an opportunity for further research related to mental models in physics learning. Further research is needed to address this gap, answer all challenges, and improve the accuracy of physics learning in constructing students' scientific mental models.

ACKNOWLEDGEMENTS

We would like to express our deepest gratitude to the Physics Education Study Program, Faculty of Teacher Training and Education, Universitas Lambung Mangkurat, for the support that has been given so that this research can be carried out properly. A sustainable academic atmosphere in supporting research and providing research support resources.

REFERENCES

Altan Kurnaz, M., & Eksi, C. (2015). An analysis of high school students' mental models of solid friction in physics. *Kuram ve Uygulamada Egitim Bilimleri*, *15*(3), 787–795. https://doi.org/10.12738/estp.2015.3.2526

Amiruddin, M. Z., Samsudin, A., Suhandi, A., & Costu, B. (2025). An analysis of first years senior high school students' mental models: A case study on the concept of uniform motion. *Journal of Education and Learning*, *19*(1), 249–256. https://doi.org/10.11591/edulearn.v19i1.21853

Anupam, A., Gupta, R., Naeemi, A., & Jafarinaimi, N. (2018). Particle in a Box: An Experiential Environment for Learning Introductory Quantum Mechanics. *IEEE Transactions on Education*, *61*(1), 29–37. https://doi.org/10.1109/TE.2017.2727442

Arifin, Z., Sukarmin, S., Saputro, S., & Kamari, A. (2025). The effect of inquiry-based learning on students' critical thinking skills in science education: A systematic review and meta-analysis. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(3), em2592. https://doi.org/10.29333/ejmste/15988

Basori, H., Suhandi, A., Samsudin, A., Kaniawati, I., & Rusdiana, D. (2020). Teaching Electrical Resistance of a Conductor Concept Using the CD-CCOI Model Supported by Dynamic Model and Dynamic Analogy in Improving the Mental Model. *Journal of Engineering Science and Technology*, 39–47.

Batlolona, J. R., & Diantoro, M. (2023). Mental Models and Creative Thinking Skills in Students' Physics Learning. *Creativity Studies*, *16*(2), 433–447. https://doi.org/10.3846/cs.2023.14743

Batlolona, J. R., Diantoro, M., & Leasa, M. (2020). Students' mental models of solid elasticity: Mixed method study. *Journal of Turkish Science Education*, *17*(2), 200–210. https://doi.org/10.36681/tused.2020.21

Batlolona, J. R., & Jamaludin, J. (2024). Students' misconceptions on the concept of sound: A case study about Marinyo, Tanimbar Islands. *Journal of Education and Learning*, *18*(3), 681–689. https://doi.org/10.11591/edulearn.v18i3.21135

Batlolona, J. R., & Souisa, H. F. (2020). Problem based learning: Students' mental models on water conductivity concept. *International Journal of Evaluation and Research in Education*, *9*(2), 269–277. https://doi.org/10.11591/ijere.v9i2.20468

Bufasi, E., & Lakrad, K. (2019). Improving teaching techniques using visual python: A case study in physics laboratories. *International Journal of Scientific and Technology Research*, *8*(12), 161–163

Cakir, M. (2008). Constructivist Approaches to Learning in Science and Their Implications for Science Pedagogy: A Literature Review. *International Journal of Environmental & Science Education*, *3*(4), 193–206

Corpuz, E. D., & Rebello, N. S. (2011). Investigating students' mental models and knowledge construction of microscopic friction. II. Implications for curriculum design and development. *Physical Review Special Topics - Physics Education Research*, *7*(2), 020103. https://doi.org/10.1103/PhysRevSTPER.7.020103

Engzell, P., Frey, A., & Verhagen, M. D. (2021). Learning loss due to school closures during the COVID-19 pandemic. *Proceedings of the National Academy of Sciences*, *118*(17), e2022376118. https://doi.org/10.1073/pnas.2022376118

Geng, X., & Su, Y.-S. (2024). Enhancing K-12 Students' STEM Learning Through the Integration of the Metaverse Into Online and Blended Environments: A Meta-Analysis. *International*

Journal of Science and Mathematics Education, *22*(S1), 111–143. https://doi.org/10.1007/s10763-024-10484-0

Hamrick, J. B., Battaglia, P. W., Griffiths, T. L., & Tenenbaum, J. B. (2016). Inferring mass in complex scenes by mental simulation. *Cognition*, *157*, 61–76. https://doi.org/10.1016/j.cognition.2016.08.012

Hansen, C., Steinmetz, H., & Block, J. (2022). How to conduct a meta-analysis in eight steps: A practical guide. *Management Review Quarterly*, *72*(1), 1–19. https://doi.org/10.1007/s11301-021-00247-4

Hurtado-Bermúdez, S., & Romero-Abrio, A. (2023). The effects of combining virtual laboratory and advanced technology research laboratory on university students' conceptual understanding of electron microscopy. *Interactive Learning Environments*, *31*(2), 1126–1141. https://doi.org/10.1080/10494820.2020.1821716

Kolaski, K., Logan, L. R., & Ioannidis, J. P. A. (2023). Guidance to best tools and practices for systematic reviews. *Systematic Reviews*, *12*(1), 96. https://doi.org/10.1186/s13643-023-02255-9

Körhasan, N. D. (2021). Investigation of the Interaction of Students' Mental Models with Peer Instructional Elements in an Undergraduate Physics Course. *Science Education International*, *32*(3), 220–230. https://doi.org/10.33828/sei.v32.i3.5

Körhasan, N. D., Erýlmaz, A., & Erkoç, Ş. (2015). The influence of instructional interactions on students' mental models about the quantization of physical observables: A modern physics course case. *European Journal of Physics*, *37*(1). https://doi.org/10.1088/0143-0807/37/1/015701

Kuhfeld, M., Soland, J., Tarasawa, B., Johnson, A., Ruzek, E., & Liu, J. (2020). Projecting the Potential Impact of COVID-19 School Closures on Academic Achievement. *Educational Researcher*, *49*(8), 549–565. https://doi.org/10.3102/0013189X20965918

Malgieri, M., Onorato, P., & De Ambrosis, A. (2017). Test on the effectiveness of the sum over paths approach in favoring the construction of an integrated knowledge of quantum physics in high school. *Physical Review Physics Education Research*, *13*(1). https://doi.org/10.1103/PhysRevPhysEducRes.13.010101

Mansyur, J., Kaharu, S. N., & Holdsworth, J. (2020). A simple approach to teach newton's third law. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 79–90. https://doi.org/10.15294/jpii.v9i1.21775

Mansyur, J., Werdhiana, I. K., Darsikin, D., Kaharu, S. N., & Tadeko, N. (2022). Students' Mental Models about the Suspending Objects in Static Fluid. *Journal of Turkish Science Education*, *19*(1), 253–283. https://doi.org/10.36681/tused.2022.1121

Marzoli, I., Colantonio, A., Fazio, C., Giliberti, M., Scotti Di Uccio, U., & Testa, I. (2021). Effects of emergency remote instruction during the COVID-19 pandemic on university physics students in Italy. *Physical Review Physics Education Research*, *17*(2), 020130. https://doi.org/10.1103/PhysRevPhysEducRes.17.020130

Mohd Yusof, M. M., Arshad, A. S. B., & . E. (2022). Identifying Students' Misconceptions of Sound Propagation. *International Journal of Academic Research in Progressive Education and Development*, *11*(4), Pages 391-405. https://doi.org/10.6007/IJARPED/v11-i4/15864

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Medicine*, *6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Nandiyanto, A. B. D., & Al Husaeni, D. F. (2021). A bibliometric analysis of materials research in

Indonesian journal using VOSviewer. *Journal of Engineering Research*. https://doi.org/10.36909/jer.ASSEEE.16037

Nandiyanto, A. B. D., Al Husaeni, D. N., & Al Husaeni, D. F. (2021). A bibliometric analysis of chemical engineering research using vosviewer and its correlation with Covid-19 pandemic condition. *Journal of Engineering Science and Technology*, *16*(6), 4414–4422.

Nongkhunsarn, A., Yuenyong, C., Tupsai, J., & Sranamkam, T. (2019). Grade 11 Student's Mental Model of Fluid and Analytical Thinking in Science Teaching Through Science Technology and Society (STS) Approach. *Journal of Physics: Conference Series*, *1340*(1), 012043. https://doi.org/10.1088/1742-6596/1340/1/012043

Nurmahasih, U., & Jumadi, J. (2023). Effect of Utilizing the PBL Model in Physics Learning on Student Learning Outcomes: A Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, *9*(6), 81–88. https://doi.org/10.29303/jppipa.v9i6.2741

Ozcan, O. (2017). Examining the students' understanding level towards the concepts of special theory of relativity. *Problems of Education in the 21st Century*, *75*(3), 263–269

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change. *Science Education*, *66*(2), 211–227.

Ravanis, K. (2019). Mental Representations of Light Propagation Time for 10- and 14-Year-Old Students: Didactical Perspectives. *Journal of Baltic Science Education*, *18*(2), 276–285. https://doi.org/10.33225/jbse/19.18.276

Sahrir, D. C., Madnasri, S., Indriyanti, D. R., & Sapitri, R. (2024). Research Trends in Ethno-STEAM-PjBL and Religion Integration oriented Educational Sustainable Development in Science Learning through Bibliometric Analysis. *Jurnal Pendidikan Sains Indonesia*, *12*(2), 403–417. https://doi.org/10.24815/jpsi.v12i2.36084

Sánchez-Azqueta, C., Cascarosa, E., Celma, S., Gimeno, C., & Aldea, C. (2019). Application of a flipped classroom for model-based learning in electronics. *International Journal of Engineering Education*, *35*(3), 938–946

Sands, D. (2021). Modeling as sensemaking: Towards a theory of modelling in physics education. *European Journal of Physics*, *42*(6). https://doi.org/10.1088/1361-6404/abcc80

Sarapak, C., & Kearns, K. (2022). Diagnosing Mental Models of Undergraduate Student and Physics Teachers: Study Case in The Momentum and Energy Conservation Principles Using Newton's Cradle. *Jurnal Pendidikan IPA Indonesia*, *11*(4), 684–691. https://doi.org/10.15294/jpii.v11i4.37695

Smela, B., Toumi, M., Świerk, K., Gawlik, K., Clay, E., & Boyer, L. (2023). Systematic literature reviews over the years. *Journal of Market Access & Health Policy*, *11*(1), 2244305. https://doi.org/10.1080/20016689.2023.2244305

Ting, F. S. T., Shroff, R. H., Lam, W. H., Garcia, R. C. C., Chan, C. L., Tsang, W. K., & Ezeamuzie, N. O. (2023). A Meta-analysis of Studies on the Effects of Active Learning on Asian Students' Performance in Science, Technology, Engineering and Mathematics (STEM) Subjects. *The Asia-Pacific Education Researcher*, *32*(3), 379–400. https://doi.org/10.1007/s40299-022-00661-6

Ubben, M. S., & Bitzenbauer, P. (2022). Two Cognitive Dimensions of Students' Mental Models in Science: Fidelity of Gestalt and Functional Fidelity. *Education Sciences*, *12*(3). https://doi.org/10.3390/educsci12030163

Wade-Jaimes, K., Demir, K., & Qureshi, A. (2018). Modeling strategies enhanced by metacognitive tools in high school physics to support student conceptual trajectories and understanding of electricity. *Science Education*, *102*(4), 711–743. https://doi.org/10.1002/sce.21444

Wei, B., Wang, H., Li, F., Long, Y., Zhang, Q., Liu, H., Tang, X., & Rao, M. (2024). Effectiveness of Problem-Based Learning on Development of Nursing Students’ Critical Thinking Skills: A Systematic Review and Meta-analysis. *Nurse Educator*, *49*(3), E115–E119. https://doi.org/10.1097/NNE.0000000000001548

Zawacki-Richter, O., Kerres, M., Bedenlier, S., Bond, M., & Buntins, K. (Eds.). (2020). *Systematic Reviews in Educational Research: Methodology, Perspectives and Application*. Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-27602-7

Zouhri, A., & Mallahi, M. E. (2024). Improving Teaching Using Artificial Intelligence and Augmented Reality. *Journal of Automation, Mobile Robotics and Intelligent Systems*, *18*(2), 57–61. https://doi.org/10.14313/jamris/2-2024/13