

How Do High School Students Perceive Magnets (Mental Models about Magnets, Magnetic Fields, and Magnetic Force)?

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Article Info	Abstract
Article history: Received: September 14, 2025 Accepted: February 15, 2026 Published: March 18, 2026 Keywords: Magnets Mental models Misconceptions This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License © 2026 Berkala ilmiah Pendidikan Fisika	This study aims to explore the initial knowledge of high school students about magnets from two schools with different PUSPRESNAS science and technology scores, namely SMA Islam NU Pujon with a score of 0 and MAN Kota Batu with a score of 50. The research sample was selected randomly from grades X and XI, with the assumption that the research sample had gained knowledge about the concept of magnets at the previous level. The research method was qualitative descriptive. Data collection was carried out through clinical interviews. The results of the interviews were analyzed and represented in the form of categorization. The findings of the interview results showed that all research samples had the same mental model about magnets, namely: 1. Magnets interact with iron, copper, and aluminum and do not interact with wood, paper, and other non-conductive materials. 2. Magnets have separate north and south poles. 3. Magnetic fields and magnetic forces depend on distance: If the magnet is closer to the object, the magnetic field and magnetic force will be stronger and vice versa. 4. Magnetic properties are only collected at the poles. 5. The strength of a magnet is determined by its size. 6. Magnetic fields are only created by magnets. 7. Field lines are only formed outside the magnet.
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INTRODUCTION

Magnetism is one of the fundamental concepts in physics that has wide applications in everyday life and modern technology (Supriyatman et al., 2018). A deep understanding of magnets, including their magnetic properties, magnetic fields, and interactions with materials and electric currents, is very important for students as a foundation for studying more complex physical phenomena (Ngazizah et al., 2024; Ramadhan et al., 2019). However, many studies show that students often experience misconceptions (conceptual errors) in understanding magnets (Munfarikha et al., 2018). This can certainly hinder their learning process (Munfarikha et al., 2018; Nur'aini et al., 2020).

Several studies reveal that students tend to form mental models that differ from the correct scientific concept when learning about magnets (Ravanis et al., 2009). Although this concept is taught from the elementary education level, many students still have difficulty understanding the basic principles of magnetism, such as the properties of

magnetic poles, magnetic fields, and the interactions between magnets and ferromagnetic as well as non-ferromagnetic materials ([Handayani, 2024](#); [Kähkönen et al., 2020](#)). These difficulties are often caused by the presence of mental models that do not align with scientific explanations formed through daily experiences or previous learning ([Mukhlisa, 2021](#); [Munfaridah et al., 2021](#)).

Mental models are internal representations built by individuals to understand, explain, and predict phenomena around them ([Hamid, 2016](#); [Kähkönen et al., 2020](#); [Maryam & Arga, 2023](#)). For example, some students believe that all metals can be attracted to a magnet or that the north and south poles of a magnet are separate without a continuous magnetic field ([Ravanis et al., 2009](#); [Ramadhan et al., 2019](#)). Such misconceptions can hinder the understanding of more complex physics concepts, such as electromagnetism and Faraday's induction ([Hamid, 2016](#); [Hamid & Pabunga, 2017](#); [Hamid et al., 2017](#)).

Here are some characteristics of mental models according to [Kähkönen et al. \(2020\)](#): 1. Mental models are not complete. 2. Each person's ability to execute their mental model is generally limited. 3. Mental models are unstable: people tend to forget the details of the system used, especially if those details are not used within the same period. 4. Mental models do not have definite boundaries: the same tools and operations can be confusing for different people. 5. Mental models tend to be unscientific. 6. Each person's mental model is limited. Some previous studies have shown that conventional teaching methods that are lecture-based and less involved in direct experimentation can reinforce misconceptions ([Mukhlisa, 2021](#)).

Students' understanding of science concepts occurs when their thinking model constructs a mental model ([Hamid & Pabunga, 2017](#)). When students study consistent material, it will generate mental models, and this will facilitate their learning process ([Maryam & Arga, 2023](#)). Inquiry-based learning approaches, interactive simulations, or the use of analogies have proven effective in improving students' mental models. One of the important implications of conceptual change in education is teaching for conceptual understanding, which cannot be achieved without diagnosing students' prior knowledge regarding the content to be taught ([Astuti et al., 2021](#); [Dinçer & Özcan, 2021](#); [Hamid, 2016](#)). Facilitating the learning process is an absolute necessity that teachers undertake to help students understand the concepts they teach in a meaningful learning process ([Greca & Moreina, 2002](#)). However, further exploration is still needed regarding how students' mental models of magnets are formed and what factors influence them, including the impact of culture, language, and visual representations in textbooks ([Munfarikha et al., 2018](#); [Munfaridah et al., 2021](#)).

A meaningful learning roadmap is learning by understanding new information ([Hamid et al., 2017](#)). With new knowledge and existing knowledge, students will form mental models regarding the context of that knowledge ([Hamid & Pabunga, 2017](#); [Maryam & Arga, 2023](#); [Supriyatman et al., 2018](#)). If the model formed by the students is correct and appropriate, then the students have the opportunity to test their model ([Ramadhan et al., 2019](#)). Conversely, if the model they build fails, such as by producing incorrect answers or predictions, then the model must be corrected ([Bodner et al., 2000](#)).

[Ramadan et al. \(2019\)](#) found that, by a four-tier test, students experienced misconceptions about magnets among 12th-grade students after the learning process. [Munfarikha et al. \(2018\)](#) found misconceptions related to gender and IQ among 12th-grade students who had received the magnet material. Previous studies on students' mental models of magnets have claimed them to be the result of a learning process. However, no one has conducted research on students' mental models of magnets as prior knowledge for analyzing appropriate learning plans that provide proper assimilation and accommodation to build students' concepts of magnets at the high school level. This research aims to diagnose students' mental models based on concepts acquired from previous levels in understanding the concept of magnets and to identify potential sources of misconceptions

that may arise. Using a qualitative approach through clinical interviews and written response analysis, this research aims to map the various models.

METHODS

This research uses a qualitative method with a qualitative descriptive approach. This research uses clinical interviews and image-based tasks, which describe their models more clearly about magnets. Both of these data sets are used for analysis to uncover students' mental models of magnets, magnetic phenomena, and magnetic interactions.

This study employed a qualitative descriptive approach to explore high school students' mental models of magnets, magnetic fields, and magnetic interactions through clinical interviews and image-based tasks. These two data sources were used complementarily to obtain an in-depth understanding of students' conceptual representations of magnetism.

The study was conducted at MAN Kota Batu and SMA Islam NU Pujon. Participants were randomly selected by physics teachers from each school, assuming that all students had previously learned magnetism concepts in earlier grades. The interview questions were adapted from previous studies with similar research focuses. Data were collected through clinical interviews and students' drawings representing their mental models. Both types of data were analyzed, reduced, and categorized to generate meaningful conclusions.

Schools were selected based on PUSPRESNAS scores, namely MAN Kota Batu for a research and technology score of 50 points and SMA Islam NU Pujon for a research and technology score of 0 points. This is done to determine students' initial concept of the magnetism of two schools with vastly different national assessment scores, as this is related to the entrance selection process for favorite schools and not. The research sample was selected randomly. The sample consists of 4 male and female students from SMA Islam Nu Pujon, Malang Regency, East Java, and 4 female students from MAN Kota Batu, East Java. The student samples in the research are aged around 16-17 years, assuming they already have preliminary knowledge about the concept of magnets and their interactions from previous levels

The data collection technique is through open-ended question interviews. The question was adopted from [Kähkönen et al. \(2020\)](#), which contains the concept of magnets, namely:

- Characteristics of a magnet (what a magnet is and how it works)
- Types of magnetic interactions (attraction, repulsion, and no interaction)
- Magnetization and demagnetization (how materials change when magnetized)
- Magnetic field (force and consequences of magnetization)
- Magnetic domain (structure, reversible polarity, and direction of field lines)

In addition to the interview, the research sample students were also given a drawing task with the following guiding questions, which will explain more clearly their concept of magnets:

- Imagine a magnet and a nail
- Draw to explain how a nail is attracted to a magnet
- Draw to explain what will happen if you place a nail near a magnet. Imagine a magnet and a nail.
- Draw a picture to explain how a nail is attracted to a magnet.
- Draw a picture to explain what will happen if you place a nail around a magnet.

The data from the clinical interviews were analyzed, with the output categorized, and the results of the drawing tasks were represented in tabular form.

To ensure data validity and trustworthiness, several strategies were employed:

1. Triangulation: Data triangulation was conducted by comparing interview responses with students' drawing representations to confirm conceptual consistency.

2. Member Checking: After transcription and preliminary interpretation, participants were asked to confirm whether the interpretations accurately represented their intended meanings.
3. Peer Review (Peer Debriefing): Two physics education researchers reviewed the interview transcripts, coding results, and mental model interpretations to provide feedback and reduce researcher bias.

These procedures strengthened the credibility and reliability of the qualitative findings.

The categorization of students' mental models followed a systematic process. First, all interview transcripts and drawing results were coded independently by two researchers with expertise in physics education. Initial codes were developed based on conceptual indicators from magnetism theory and previous mental model studies.

Next, the codes were grouped into mental model categories representing students' levels of conceptual understanding. To test inter-rater reliability, the coding results from both raters were compared using percentage agreement. The agreement level reached above 85%, indicating high consistency between raters. Discrepancies were discussed until consensus was achieved. The finalized categories were then used to classify each student's mental model, and the results were presented in tabular and visual forms

Data were collected from interview results, and then the data from the clinical interviews were analyzed by comparing each interview result with each participant, identifying similarities and differences in each participant's interview results and then identifying key findings, namely similarities between interview results and different findings as findings that must be explored in depth regarding the missed context, and drawing conclusions in the form of categories and figures in tabular form to represent students' mental models of magnets.

Data analysis followed three main stages: data reduction, data display, and conclusion drawing. Interview and drawing data were reduced through coding and categorization. The results were then displayed in tables and figures representing mental model categories. Finally, conclusions were drawn by interpreting patterns and differences in students' mental models across the two schools

This study was conducted through clinical interviews with four students randomly selected from both MAN Kota Batu and SMA Islam NU Pujon. In addition to the interview results, the researcher also asked the research sample students to describe their mental models of magnets, magnetic fields, and magnetic interactions. From these two sets of data, data reduction and categorization were performed, and conclusions were drawn regarding the mental models of high school students about magnets from the two schools, which had significantly different Puspresnas scores

RESULTS AND DISCUSSION

Based on the comparison of interview and drawing data, seven dominant categories of students' mental models regarding magnetism were identified:

1. Magnets interact with iron, copper, and aluminum, but not with wood, paper, or other non-conductive materials.
2. Magnets have separate north and south poles.
3. Magnetic fields and magnetic forces depend on distance.
4. Magnetic properties are only concentrated at the poles.
5. Magnetic strength is determined by size.
6. Magnetic fields are only created by magnets.
7. Magnetic field lines only form outside the magnet.

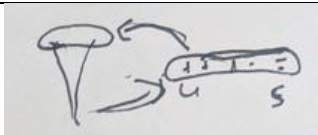
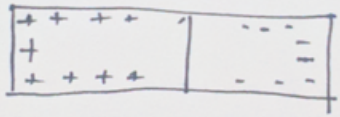
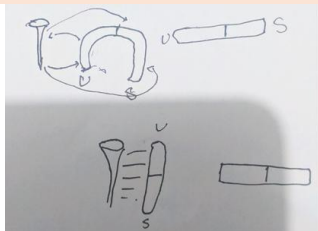
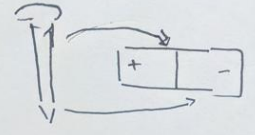
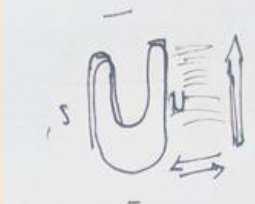
The following is the result of a personal interview regarding magnets, magnetic fields, magnetic forces, and magnetic interactions, represented in Table 1.

Table 1 Results of personal interviews

Name	Magnets interact with iron, copper, and aluminum	Magnets have separate north and south poles.	Magnetic fields and magnetic forces depend on distance	Magnetic properties are only concentrated at the poles.	Magnetic strength is determined by its size	Magnetic fields are only created by magnets	Magnetic fields only form outside magnets
M.A	V	V	V	V		V	V
A.I	V	V	V	V	V	V	V
K.D	V		V	V		V	V
K.J	V	V	V	V		V	V
S.S	V	V	V	V	V	V	V
A.N	V	V	V	V	V	V	V
V.S	V	V	V	V	V	V	V
S.T	V	V	V	V	V	V	V

All students in the sample described the interaction between nails and magnets in the same way, as represented in Table 2.

Table 2 Results of the representation of the interaction between nails and magnets

Name	Gender (M/F)	School Name	Class	Model Mental Representation
M.A	M	SMA Islam NU Pujon	X-1	
A.I	F	SMA Islam NU Pujon	XI-5	
K.D	M	SMA Islam NU Pujon	XI-5	
K.J	F	SMA Islam NU Pujon	X-2	
S.S	F	MAN Kota Batu	X-P	
A.N	F	MAN Kota Batu	X-P	

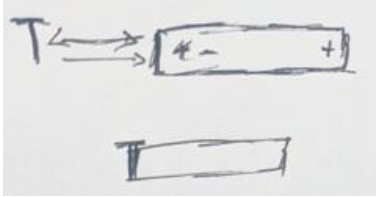
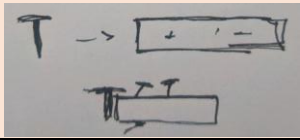
Name	Gender (M/F)	School Name	Class	Model Mental Representation
V.A	F	MAN Kota Batu	XI-F	
S.T	F	MAN Kota Batu	XI-E	

Table 2 shows the results of the sample students' representations of the interaction between magnets and nails. All students depicted that nails and magnets interact naturally. None of the drawings showed magnetic field lines either inside or outside the magnet. All drawings identified magnets as containing both positive and negative charges.

Based on mental model theory ([Chi, 2005](#); [Vosniadou, 2013](#)), students' mental models can be classified into three levels: naive model, concepts based on everyday experience without scientific structure. Synthetic model, partial scientific concepts mixed with everyday or intuitive reasoning. Scientific model, concepts consistent with scientific explanations. The students' responses in this study predominantly fall into the naive and synthetic mental model levels, while no participant demonstrated a fully scientific mental model

Interpretation of Each Finding: 1. Interaction only with certain metals: students believed magnets interact with iron, copper, and aluminum. Scientifically, magnets strongly interact mainly with ferromagnetic materials such as iron, nickel, and cobalt. This misconception reflects an everyday intuitive mental model, classified as a naive model, because students generalized interaction based on visible experiences. 2. Separate north and south poles. This concept aligns partially with scientific knowledge. However, students viewed poles as independent entities rather than inseparable parts of a magnetic dipole. This reflects a synthetic mental model, where scientific terminology is used without a correct conceptual structure. 3. Magnetic force depends on distance. This statement is scientifically correct in principle, but students could not explain the inverse-square or field-based nature of the interaction. Thus, this represents a synthetic model, combining correct observation with incomplete theoretical understanding. 4. Magnetic properties only at the poles. This misconception reflects an intuitive, naive model, where students focus only on visible attraction at the poles, ignoring the existence of magnetic fields throughout the magnet. 5. Magnetic strength determined by size. This is an everyday mental model, assuming that larger objects must be stronger. This reasoning reflects a naive model because it ignores material composition and magnetic domain alignment. 6. Magnetic fields are only created by magnets. This misconception shows that students do not understand electromagnetic induction and current-generated magnetic fields. This represents a naive mental model. 7. Magnetic field lines only outside the magnet. Students' drawings did not show internal field lines, indicating an incomplete representation of magnetic domains. This corresponds to a synthetic mental model, as students recognized field lines but misunderstood their continuity.

Overall, students' mental models of magnetism in this study can be categorized as: Naive mental models dominated by everyday experiences and visual intuition. Synthetic mental models: partial scientific knowledge mixed with misconceptions, and scientific mental models not observed in any participant. Thus, the mental models of all students fall

into the incorrect and incomplete categories, confirming that their understanding of magnetism is not yet scientifically structured.

These findings are consistent with [Kähkönen et al. \(2020\)](#) among Finnish middle school students, where the mental models of 12 research participants indicated that magnetic interactions are only attractive and repulsive, with the magnetic model consisting only of poles and charges. [Hamid et al. \(2017\)](#) found that students' mental models of magnets consisted of 44% scientific, 52% everyday life analogies, and 4% intuitive. After the scientific learning process, the changes were as follows: 20% remained consistently correct, 16% remained consistently incomplete, 8% changed from incorrect to incomplete, 32% changed from incomplete to complete, 4% changed from complete to incorrect, and 4% changed from incorrect to complete. [Munfarikha et al. \(2018\)](#) identified three mental models of high school students based on IQ, gender, and grade level: Model A, “magnet as an attractor of iron and metal”; Model B, “magnet as a field”; and Model C, “magnet as an electric charge.”

Although the two schools differed significantly in PUSPRESNAS scores, students from both schools demonstrated similar mental model structures. This indicates that national academic achievement does not necessarily guarantee conceptual understanding of magnetism. Students' mental models are primarily shaped by everyday experiences rather than structured scientific learning.

Students' knowledge of magnetism was also found to be fragmented and disconnected from electricity concepts. None of the participants explained that electric current can generate magnetic fields. This conceptual separation indicates the absence of hierarchical conceptual integration, which is essential for forming scientific mental models. According to conceptual change theory, when concepts are not hierarchically organized, students tend to retain fragmented and unstable knowledge structures, resulting in persistent misconceptions.

CONCLUSION

The interview findings indicate that there is no difference in students' mental models of magnets between the two schools with vastly different science and technology scores. The mental models of students in both schools fall into the category of incomplete and unscientific. These findings can be used as preliminary data or diagnostic assessments in developing appropriate learning models to facilitate students in building a comprehensive understanding of magnets in the upcoming 12th grade. These findings indicate that physics instruction on magnetism has not yet facilitated the transformation from naive and synthetic mental models into scientific mental models. Therefore, instructional strategies should explicitly focus on connecting magnetism with electricity, visualizing magnetic field continuity, addressing misconceptions related to material properties, and using model-based and inquiry-based learning approaches.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, NM and RN; methodology, F; formal analysis, AI; writing preparation of the original draft, ML and NM.

AI DISCLOSURE STATEMENT

The authors used OpenAI during the preparation of this work for language refinement and initial drafting support. After using the tool/service, the author thoroughly reviewed and edited the content as needed and takes full responsibility for the content of the publication.

The authors declare that this research was prepared, researched, written, and edited without the aid of artificial intelligence (AI) techniques.

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