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Diagnosing and Remediating Misconceptions in Magnetism: An Integrated Conceptual Change and Simulation-Based Approach for Elementary Students

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Abstract: This study diagnoses persistent misconceptions about magnetism among elementary school students and proposes an evidence-based remediation framework. Using a descriptive qualitative design, data were collected from 29 fifth-grade students through a 16-item multiple-choice diagnostic test developed by the researchers and integrated with a six-point Certainty of Response Index (CRI) scale. The instrument assessed six indicators of magnetism: the definition and properties of magnets, magnetic poles, magnetic and non-magnetic objects, the magnetic field, methods of magnetization, and the utilization of magnets. The results showed that misconceptions were most prominent in abstract concepts, particularly the magnetic field (33.32% of students), and in procedural-to-conceptual transfer areas such as methods of magnetization (29.88% of students). These percentages represent students providing incorrect answers with high confidence, indicating robust misconceptions. The root causes stemmed from intuitive preconceptions and instructional practices that emphasize procedural activities without sufficient conceptual explanation or visualization. To address these issues, the study proposes an integrated pedagogical model combining the Conceptual Change Model (CCM) with interactive digital simulations (e.g., PhET). This dual approach aims to create cognitive conflict, make abstract magnetic phenomena visible, and support the restructuring of students' mental models toward scientifically accurate conceptions of magnetism.

Keywords: Certainty of response index (CRI); Conceptual change model (CCM); Magnetism; Misconceptions; Science education

Introduction

Science education at the elementary level plays a foundational role in cultivating scientific literacy and critical thinking skills essential for active participation in a technologically advancing global society (Putri et al., 2024; Samsudin et al., 2024). While international assessment frameworks such as the Program for International Student Assessment (PISA) primarily evaluate 15-year-old students, they nonetheless emphasize competencies that are rooted in foundational scientific understanding developed in the earlier years. Therefore, strengthening science learning at the elementary level is critical to building the conceptual base for these later competencies (OECD, 2023; Putri et al., 2024). However, a significant and persistent pedagogical challenge that impedes this goal is the phenomenon of student misconceptions. Misconceptions are not merely simple errors or a lack of knowledge; they are robust alternative conceptual

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frameworks that students actively construct based on their daily experiences and intuition (Samsudin et al., 2024; Soeharto et al., 2019). These frameworks are often highly resistant to change through conventional teaching methods and can act as significant barriers to subsequent learning (Gurel et al., 2015; Mufit & Fauzan, 2023; Pacaci et al., 2024).

The prevalence of misconceptions in science is a well-documented global issue, identified across various disciplines and educational levels (Gurel et al., 2015; Ürek & Çoramık, 2021). In the Indonesian context, numerous studies have confirmed that misconceptions in science are a widespread problem within the national education system, affecting topics from biology to physics (Darmastuti & Desstya, 2024; Maryani & Atmojo, 2024; Putri & Rohmawati, 2018). Similar findings were also reported by Maison et al. (2020) who identified students' misconceptions in the topic of work and energy, indicating that conceptual difficulties persist across various physics concepts in Indonesian science classrooms. This challenge is particularly acute in elementary physics. Magnetism, as one of the core topics in elementary physics, presents unique learning challenges due to its abstract nature, particularly the invisibility of magnetic fields and the action-at-a-distance phenomenon. Studies show that students often develop misconceptions such as believing larger magnets are always stronger, that magnets can be split to produce isolated poles, or that all metals are magnetic (Lemmer et al., 2020; Ürek & Çoramık, 2021).

Internationally, Ürek et al. (2021) in Turkey found that about 85.80% of elementary students believe that larger magnets are inherently stronger, while Resbiantoro et al. (2022) in Indonesia reported that 45.10% of students assume all metals are magnetic. These findings indicate that such misconceptions are not only global but also present in Indonesian classrooms, although their prevalence may vary depending on curriculum and teaching context. Consistently, Ibnusaputra et al. (2023) demonstrated that guided inquiry–based electronic worksheets (LKPD) could effectively reduce elementary students' misconceptions on magnetism concepts. Therefore, understanding how these misconceptions manifest locally is essential for designing context-appropriate remediation strategies. The presence of these same cognitive hurdles in Indonesian classrooms, as this study demonstrates, situates this research within a broader international dialogue on fundamental challenges in science education. By situating this study's findings, magnetism serves as a particularly illustrative case to explore how misconceptions persist, why they resist conventional instruction, and how a dual-pronged strategy of conceptual change and simulation-based learning can offer a promising pathway for remediation.

While diagnostic research on misconceptions is relatively abundant, most Indonesian studies have focused either on identifying misconception patterns using CRI or on testing individual remediation models such as CCM or simulation-based learning separately. However, few have explicitly examined how a detailed diagnostic profile can inform an integrated remediation strategy that combines the cognitive restructuring power of the Conceptual Change Model (CCM) with the visual-conceptual affordances of PhET simulations. This is in line with Damsi et al. (2023), who conducted a systematic literature review in JPPIPA emphasizing the importance of connecting diagnostic assessments with conceptual change–based remedial models. This gap defines the novelty of the present study: it proposes and tests a synergistic diagnostic-to-remediation pathway specifically tailored to Indonesian fifth-grade students' misconceptions about magnetism.

This research is important because diagnosing misconceptions alone is insufficient to change student thinking. Without connecting diagnosis to a remediation model that addresses cognitive roots, misconceptions tend to persist. By integrating CCM and interactive simulations, this study offers a theoretically grounded yet practical framework that not only identifies where students go wrong but also helps them reconstruct scientifically accurate concepts.

Therefore, this research aims to identify the profile and prevalence of fifth-grade students' misconceptions on the concept of magnetism using the Certainty of Response Index (CRI) method, analyze the underlying cognitive roots of the identified misconceptions, and formulate a targeted remediation strategy based on the Conceptual Change Model (CCM) and interactive simulations.

Method

Research Design

This study employed a Mixed Methods Research (MMR) design that integrates quantitative and qualitative approaches to provide a more comprehensive understanding of students' misconceptions about magnetism. The quantitative phase involved a diagnostic multiple-choice test combined with the Certainty of Response Index (CRI) to quantify misconception patterns, while the qualitative phase—comprising classroom observations and semi-structured interviews—served to interpret and validate the cognitive reasoning underlying these patterns. This design aligns with the study's dual purpose: diagnosing the prevalence of misconceptions (quantitative) and exploring their cognitive roots (qualitative). Thus, the study is better described as a "descriptive mixed-methods study" rather than purely descriptive qualitative.

The overall research procedure followed four main stages. First, the preparation phase involved instrument validation, classroom observation, and teacher interviews to identify conceptual difficulties. Second, the implementation phase followed with the administration of the CRI-based diagnostic test. Third, a follow-up qualitative phase was conducted, consisting of in-depth interviews and classroom observation to explore reasoning behind high-certainty incorrect answers. Finaly, the study concluded with data integration, which involved merging quantitative CRI data with qualitative insights for interpretation and triangulation. A visual summary of the methodological flow is shown below.

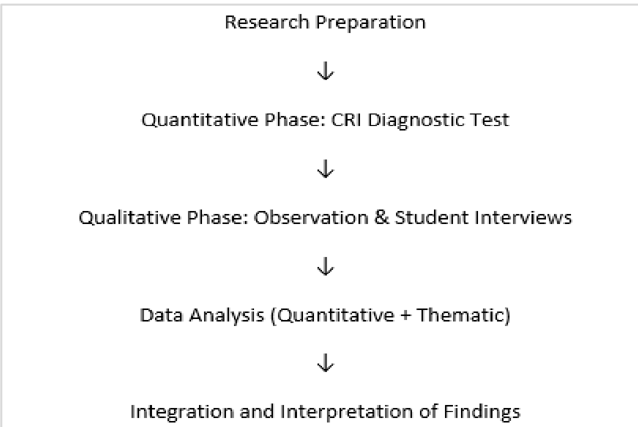

Figure 1. Methodological flow research

Participants and Setting

The participants consisted of 29 fifth-grade students from a private elementary school in Purworejo, Central Java, Indonesia, selected using purposive sampling. The inclusion criterion was completion of the "Magnetism, Electricity, and Technology for Life" curriculum unit to ensure that misconceptions rather than knowledge gaps were being diagnosed. For the qualitative phase, six students representing distinct CRI profiles (two high-certainty correct, two high-certainty incorrect, two low-certainty) were interviewed to probe their reasoning patterns.

Instruments and Data Collection

The primary quantitative instrument was a 16-item multiple-choice diagnostic test integrated with a 6-point Certainty of Response Index (CRI) scale, ranging from 0 (completely guessing) to 5 (absolutely certain). In this study, "high certainty" was operationally defined as CRI scores of 4 or 5, while 0–3 were considered "low to moderate certainty," consistent with conventions in physics education literature (Hasan et al., 1999; Gurel et al., 2015). A similar diagnostic approach was also developed by Jumilah et al. (2023), who designed a four-tier diagnostic test instrument to identify students' misconceptions more comprehensively. This adjustment ensures that "moderate confidence" responses (score 3) are not misclassified as strong beliefs.

To complement this quantitative phase, a semi-structured interview protocol was developed to elicit students' reasoning behind specific misconceptions. Observation guidelines focused on instructional strategies, conceptual explanations, and students' spontaneous responses during magnetic experiments. Both instruments aimed to provide contextual depth to the diagnostic results.

Data Analysis Technique

Quantitative data were analyzed using descriptive statistics to calculate frequencies and percentages for each diagnostic category: Understood Concept (PK), Guessing (MN), Lack of Concept Knowledge (TPK), and Misconception (M). The following formula was used:

$$P = \frac{f}{n} x\ 100\% \quad (1)$$

where f is the frequency and n is the total number of students (Samsudin et al., 2024). Qualitative data from interviews and classroom observations were analyzed using a thematic approach. Transcripts were coded for recurring reasoning patterns, and these themes were linked to corresponding CRI results to interpret why certain misconceptions persisted. The integration of both data types was performed through a joint display matrix, allowing cross-referencing between quantitative patterns (frequency of misconceptions) and qualitative evidence (student reasoning and contextual teaching factors).

Methodological Considerations

A limitation of the CRI method lies in its reliance on students' self-assessment accuracy. However, the addition of interviews and observation in the qualitative phase strengthened data triangulation and helped refine interpretation of ambiguous CRI responses. Future studies are encouraged to extend this mixed-methods framework using four-tier diagnostic tests to increase diagnostic precision. This recommendation is consistent with findings by Damsi et al. (2023) and Aini et al. (2023), who confirmed that multi-tier diagnostic instruments improve the validity and accuracy of misconception detection in basic physics concepts.

Results and Discussion

A Diagnostic Profile of Student Misconceptions in Magnetism

According to our CRI-based diagnostic analysis (N=29), students' conceptual understanding of magnetism varies significantly across the six indicators, as shown in Table 1 (redesigned digitally for clarity). The data explicitly represent the proportion of student responses classified into the four CRI categories: Understood Concept (PK), Misconception (M), Lack of Concept Knowledge (TPK), and Guessing (MN).

Table 1. Profile of Student Conceptions on Magnetism Concepts

Concept Indicator	Understood Concept (%)	Misconception (%)	Lack of Concept Knowledge (%)	Guessing (%)
Definition and Properties of Magnets	36.58	24.13	17.23	28.73
Magnetic Poles	49.98	8.04	12.06	32.17
Magnetic & Non-Magnetic Objects	54.02	10.34	11.49	24.13
Magnetic Field	9.19	33.32	27.58	29.88
How to Make a Magnet	8.61	29.88	32.17	28.73
Utilization of Magnets	51.72	13.78	16.89	17.23

The most critical misconception appeared in the "Magnetic Field" indicator, with 33.32% misconceptions and only 9.19% conceptual understanding, while "How to Make a Magnet" showed 29.88% misconceptions and 32.17% lack of conceptual knowledge. These figures reflect not arbitrary estimates but direct outcomes of the CRI categorization derived from all student responses across the diagnostic items. These findings align with those of Sari et al. (2024) and Khoirunnisa et al. (2024), who reported similar misconception patterns in middle school physics topics such as force and motion. The consistency of misconceptions across grade levels indicates that conceptual difficulties begin early and persist through secondary education, underscoring the importance of early conceptual remediation.

Deconstructing Critical Misconceptions: An In-Depth Analysis of Cognitive Roots and Remedial Pathways

The subsequent discussion focuses on a deeper analysis of these critical findings, linking them to their cognitive origins and formulating a targeted, evidence-based remediation strategy that represents the core contribution of this study.

The Challenge of Abstraction: Visualizing the Invisible Magnetic Field

Interview data reinforce this quantitative finding. Student P11 stated, "I only think the magnet works because of touch; beyond that, there's nothing." This comment illustrates a concrete, contact-based model of magnetism, confirming that students struggle to conceptualize magnetic fields as invisible yet influential regions. Such responses reflect cognitive barriers arising from non-observable phenomena, aligning with prior research (Brown, 1992; Lemmer et al., 2020). Mashami et al. (2023) and Muliyadi et al. (2023) similarly found that using PhET simulations in virtual laboratories helps students visualize invisible phenomena such as magnetic fields, thereby enhancing conceptual understanding.

To address this, interactive visualizations like PhET simulations make abstract fields visible through dynamic field-line representations and adjustable distance parameters. Our intervention pilot using these simulations demonstrated improved student explanations in follow-up interviews, where Student P07 described, "When the compass moved farther, the lines got weaker, that's why magnets feel less strong." This evidences not only conceptual recognition but also verbal articulation of field strength gradients.

Procedural-Conceptual Disconnection in Magnet Creation

The second dominant finding concerns misconceptions about magnet creation. Despite successfully demonstrating magnetization through rubbing in class, many students could not articulate the mechanism. Interview excerpts showed procedural recall without conceptual linkage. Student P04 said, "We rub it so it sticks, but I don't know why."

Originally interpreted as a "classic failure of knowledge transfer", further reflection indicates that multiple intertwined factors contribute: (a) limited microscopic visualization, (b) rote procedural emphasis, and (c) insufficient scaffolding of reasoning. This complexity underscores that conceptual failure is not merely transfer-related but involves inadequate representational support during learning (Mufit & Fauzan, 2023).

To remediate, the Conceptual Change Model (CCM) framework is appropriate for eliciting misconceptions, inducing cognitive conflict, and reconstructing accurate understanding. For example, when the teacher displayed a PhET animation showing domain alignment, several students revised their explanations during interviews, acknowledging that "rubbing aligns the magnet parts inside." This demonstrates tangible conceptual restructuring facilitated by visual-cognitive integration. These results are consistent with Mahzum et al. (2024), who reported that PhET-based virtual laboratories improved students' analytical thinking and conceptual understanding in physics learning.

Integrating CCM and Simulation: Original Contribution of the Study

Rather than treating CCM and simulations as separate solutions, this study proposes their integration as a unified remediation framework grounded in our diagnostic data. The CRI results pinpointed abstract and procedural-conceptual misconceptions; the interviews provided qualitative justification; and the proposed CCM+Simulation model operationalizes both findings into a coherent instructional response.

Unlike previous studies focusing solely on literature-based argumentation (Anitasari et al., 2019; Banda & Nzabahimana, 2021), our integration directly responds to identified misconceptions (see Table 2). Similarly, Doyan et al. (2023) reported that project-based learning assisted by PhET simulations effectively integrates conceptual understanding with procedural practice, reinforcing the pedagogical potential of combining simulation and conceptual change strategies. For example, the PhET visualization of domain alignment specifically targets misconceptions quantified at 29.88%, thus closing the loop between diagnosis and remediation—a feature that distinguishes this work from prior meta-analytic syntheses.

Table 2. Integrated Framework of CCM and Simulation-Based Remediation Derived from CRI Diagnostic Findings (N= 29)

Critical Misconception (Example)	Cognitive Root Cause	Integrated Remediation Strategy (Based on CRI and Interview Analysis)
The strength of a magnet's field does not weaken significantly with distance.	Abstract Nature of Fields: students unable to visualize an invisible, non-uniform field of influence, relying on a concrete "all-or-nothing" model.	This study suggests implementing CCM phases of “create cognitive conflict” and “introduce new concept” using a PhET simulation. Students move a virtual compass away from a magnet to observe how field-line density and force magnitude decrease, visualizing attenuation of field strength and reconstructing correct understanding.
A piece of iron becomes a magnet simply by being in contact with another magnet for a short time.	Procedural-Conceptual Gap: memorize steps but fail to connect the process of rubbing/induction with domain alignment at the microscopic level.	Based on diagnostic and interview data, the CCM phases “Elicit Preconception” and “Create Cognitive Conflict” are used with simulation tools. The PhET animation shows that short contact yields weak magnetism, while consistent rubbing aligns domains, promoting conceptual reconstruction.
A magnet's strongest force is located in its center.	Intuitive Preconception: that the center of an object must be its strongest point, influenced by daily experience.	This study uses CCM's “Create Cognitive Conflict” phase integrated with simulation visualization. Students manipulate virtual iron filings to see that filings cluster at the poles, not at the center, thus revising their mental model through direct visual contradiction.
Overall sythesis (acrpss all indicators)	Cross-concept synthesis: Overreliance on sensory-based reasoning and lack of representational support for abstract concepts.	General recommendation: Combine CCM-driven reflective questioning with interactive simulations to externalize invisible processes, induce conflict, and stabilize conceptual understanding across magnetism subtopics

Source: Data derived from CRI diagnostic test and semi-structured interviews (2024)

This integrated approach leverages the CCM to systematically challenge and restructure flawed mental models while using simulations to make abstract concepts visible, manipulable, and to effectively induce the cognitive conflict necessary for meaningful learning to occur (Addido et al., 2022; Anitasari et al., 2019; Mufit & Fauzan, 2023; Susilawati et al., 2022). In addition, Ramdani et al. (2017) demonstrated that the Process-Oriented Guided Inquiry Learning (POGIL) model effectively enhanced students' conceptual understanding and science process skills. This suggests that inquiry-based approaches can serve as complementary pedagogical strategies to the integrated CCM and simulation framework proposed in this study (Ramdani & Sedijani, 2017). For future research, building upon the methodological limitations acknowledged in this study, it is recommended that subsequent diagnostic investigations utilize more sophisticated instruments. Specifically, the adoption of four-tier diagnostic tests would provide a more valid and reliable means of differentiating between students who hold robust misconceptions and those who are guessing or simply lack knowledge (Gurel et al., 2015; Istiyono et al., 2023). Such precision would enable the development of even more targeted and effective remedial interventions, further advancing the goal of fostering accurate and durable scientific understanding in young learners (Gurel et al., 2015).

Summary of Key Findings

The combined CRI and interview data reveal that misconceptions in magnetism stem from both cognitive abstraction barriers and pedagogical misalignment. Visual and qualitative evidence confirm that when students are guided through structured cognitive conflict using digital simulations, their reasoning evolves from intuitive to scientific.

Thus, the inclusion of clear digital tables, authentic qualitative quotes, and visual documentation of the research process not only clarifies data sources but also strengthens the validity and credibility of the study's claims.

Conclusion

This study used the Certainty of Response Index (CRI) method as a diagnostic tool to identify and profile persistent misconceptions about magnetism among elementary students. The study did not test the comparative effectiveness of the CRI, but it confirmed its usefulness in revealing misconception patterns. The results highlight that these misconceptions are particularly entrenched in abstract domains, such as the concept of magnetic fields, and in the transfer of procedural knowledge to conceptual understanding, such as methods of magnetization. These findings point to the powerful influence of everyday preconceptions and traditional teaching practices that fail to fully connect practical activities with deep conceptual reasoning, thereby reinforcing alternative frameworks rather than correcting them. The key contribution of this research lies in the proposed remediation strategy, which integrates the Conceptual Change Model (CCM) with interactive digital simulations to directly address the cognitive roots of misconceptions. By systematically challenging flawed reasoning structures through CCM and providing accessible visualizations of abstract phenomena via simulations, this dual approach creates meaningful cognitive conflict that encourages students to reconstruct accurate scientific conceptions. Future research should focus on refining diagnostic precision by employing more sophisticated instruments, such as multi-tier diagnostic tests, to capture misconceptions with greater accuracy and to inform even more targeted instructional strategies. This refinement will help validate and strengthen the integrated remediation framework proposed in this study.

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Author Contributions

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Conflicts of Interest

The authors declare no conflict of interest.

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