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Teachers' Perspectives on Students' Conceptual Difficulties in Magnetism: Challenges and Instructional Implications

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Abstract – *Magnetism is a fundamental component of physics education that underpins both scientific literacy and technological innovation. Yet, research consistently shows that students struggle to achieve a deep conceptual understanding of this topic. Persistent misconceptions, particularly in visualizing three-dimensional vector relationships and applying the right-hand rule, hinder students' ability to transfer knowledge to novel contexts. Addressing these difficulties requires not only innovative instructional media but also insights from teachers who directly observe and manage such challenges in classroom practice. This study aimed to explore high school physics teachers' perspectives on the difficulties of teaching magnetism and their interpretations of students' learning barriers. Using a qualitative descriptive design, data were collected through semi-structured interviews with three teachers from different regions of Indonesia, each with four to seven years of teaching experience. Thematic analysis of the interview transcripts revealed two major findings: teachers reported significant limitations in instructional resources, which restricted their ability to dynamically depict vector orientations and forces; and students were observed to rely on rote memorization, struggle with spatial visualization, and confuse the applications of the right-hand rule in different contexts. These results highlight the intersection of pedagogical and cognitive barriers, showing how inadequate media directly contributes to persistent student misconceptions. The novelty of this study lies in foregrounding teachers' experiences, thereby filling a gap in the literature that has predominantly focused on student-centered analyses. The conclusions emphasize the need for interactive, spatially explicit media, supported by structured pedagogical guidance, to strengthen magnetism learning. This study contributes to physics education by integrating teachers' perspectives into efforts to design feasible and effective instructional interventions.*

Keywords: *high school, interactive learning media, magnetism, right-hand rule, spatial visualization*

I. INTRODUCTION

Magnetism constitutes one of the central pillars of physics education due to its dual role as a fundamental scientific concept and a key driver of technological advancements. A robust understanding of magnetic principles enables learners to explain natural phenomena such as the

Earth's magnetic field, while also providing the conceptual basis for the functioning of modern devices such as electric motors, magnetic levitation trains, and medical imaging technologies like Magnetic Resonance Imaging (MRI) (Bordianu & Samoilescu, 2019; Hoffmann & Moldwin, 2022; Yalçin & Sadik, 2024). Mastery of this domain enables students not only to comprehend the scientific underpinnings of magnetism but also to develop essential analytical skills for exploring correlations between electricity and magnetism, and for applying these insights to everyday contexts. Beyond fostering immediate conceptual knowledge, an effective study of magnetism can prepare learners for advanced studies in physics and engineering, while simultaneously equipping them with competencies required for technological innovation (Özdes Koca, 2022; Boisandi & Alsagaf, 2023). Thus, magnetism is not merely a theoretical topic in physics curricula but a vital steppingstone for nurturing scientific literacy and future-oriented innovation capacity.

Despite the recognized importance of magnetism, educational research continues to report persistent learning challenges in this area. Students often fail to develop a deep conceptual understanding and instead rely on memorization when faced with problems that require the application of magnetic concepts (Munfarikha et al., 2018; Kaliampos et al., 2021; Özdemir & Coramik, 2018). Misconceptions are widespread, ranging from fundamental misunderstandings of magnetic poles to more complex misinterpretations of vector relationships in electromagnetic phenomena (Silviani et al., 2020; Ürek & Çoramık, 2021). Weaknesses in vector algebra and spatial reasoning exacerbate these challenges, as students struggle to connect theoretical representations with practical applications (Stepanović et al., 2019; Andriani et al., 2022). This recurring difficulty underscores the need for instructional strategies that transcend rote memorization and emphasize active visualization, spatial reasoning, and hands-on exploration to foster durable conceptual understanding.

One of the most persistent problems reported in physics education research relates to the application of the right-hand rule (RHR) in determining the direction of forces, fields, and currents in magnetism. While the rule itself is straightforward, its correct application requires strong three-dimensional visualization skills, a competency that many students lack. Teachers frequently observe that students, despite recalling the verbal description of the rule, experience significant difficulty in executing it in practice, particularly in distinguishing between its application for current-carrying wires versus moving charges (Karadağ & Ünlü Yavaş, 2021; Kaliampos et al., 2021; Han et al., 2021). This confusion is exacerbated by the reliance on two-dimensional textbook diagrams, which inadequately convey the spatial relationships between vectors of velocity, magnetic field, and force (Klein et al., 2021; Malgieri et al., 2021). As a result, students often resort to rote memorization of examples rather than cultivating transferable conceptual reasoning, rendering them prone to errors when presented with novel problems (Kähkönen et al., 2020).

Educators have attempted to mitigate these difficulties by introducing alternative teaching strategies and resources. Traditional approaches, such as demonstrations with bar magnets, iron filings, or current-carrying wires, have been staples of classroom practice. However, these methods can only partially depict magnetic phenomena and typically fail to capture dynamic vector relationships (Kaliampos et al., 2021). Similarly, static images and videos, though widely used, lack the interactivity necessary to engage students in constructing accurate mental models of magnetic processes (Karadağ & Ünlü Yavaş, 2021). These instructional shortcomings have sparked growing interest in integrating digital and interactive media as complementary tools for enhancing spatial reasoning and supporting the visualization of abstract concepts.

In response to these pedagogical challenges, researchers have explored the potential of digital simulations, augmented reality (AR), and blended learning models to improve students' conceptual mastery of magnetism. Meta-analyses and thematic reviews consistently demonstrate that AR applications can enhance both motivation and conceptual understanding in science education (Batdi & Talan, 2019; Garzón & Acevedo, 2019; Silva et al., 2023; Syskowski et al., 2024). Similarly, digital simulations have been shown to foster improved comprehension of abstract concepts by enabling learners to interact with dynamic, three-dimensional models (Nandani & Raturi, 2024). Studies such as Prahani et al. (2022) provide evidence that integrating digital problem-based learning with interactive animations enhances problem-solving skills in topics related to magnetic fields. Nevertheless, caution is warranted, as overreliance on purely digital tools without hands-on experience risks producing superficial or incomplete conceptual understanding (Malgieri et al., 2021; Kähkönen et al., 2020). For this reason, blended instructional approaches that combine traditional experimentation with interactive simulations are increasingly recommended as optimal strategies for improving students' spatial reasoning and conceptual accuracy (Chen, 2019; Han et al., 2021; Letina & Vasilj, 2021).

Taken together, these studies highlight both the promise and limitations of existing instructional practices in magnetism. On the one hand, they confirm that difficulties in applying the right-hand rule, comprehending the Lorentz force, and visualizing three-dimensional vector interactions persist stubbornly in secondary physics education (Özdemir & Coramik, 2018; Klein et al., 2021; Malgieri et al., 2021). On the other hand, they demonstrate that innovative strategies, particularly those incorporating interactive or blended media, can play a critical role in addressing these challenges. However, a notable gap in the literature is the limited focus on teachers' perspectives in understanding these difficulties. While the majority of prior research emphasizes student-centered analyses of misconceptions and learning barriers (Munfarikha et al., 2018;

Silviani et al., 2020; Ürek & Çoramık, 2021; Guerra-Reyes et al., 2024), fewer studies have systematically investigated the challenges teachers face in delivering magnetism content and their interpretations of students' struggles. This omission is significant, as teachers' perspectives are indispensable for identifying practical barriers in classroom instruction, for understanding the constraints of available instructional media, and for designing interventions that are feasible in real-world teaching environments. By integrating these perspectives, educational research can more effectively bridge the gap between theoretical innovations and classroom practice.

The present study seeks to address this gap by examining the experiences of high school physics teachers in teaching magnetism, with a particular emphasis on their perspectives regarding students' conceptual difficulties. By employing a qualitative descriptive approach and drawing on thematic analysis of semi-structured interviews, this research provides empirical evidence on how teachers conceptualize both their own instructional challenges and the learning barriers encountered by students. The novelty of this study lies in its dual focus: first, in elucidating the practical challenges teachers face in employing instructional media to support the visualization of abstract magnetic phenomena; and second, in identifying teachers' interpretations of students' misconceptions, particularly in applying the right-hand rule. In doing so, this research contributes to the broader literature by highlighting the intersection of pedagogical constraints and cognitive barriers in magnetism education. Ultimately, the findings aim to inform the design of more effective, context-sensitive teaching strategies and interactive learning resources that can enhance students' spatial reasoning and conceptual understanding of magnetism, while also supporting teachers in overcoming long-standing instructional challenges.

II. METHODS

This study adopted a qualitative descriptive research design to investigate the challenges faced by high school physics teachers in teaching magnetism and to explore their perspectives on students' conceptual difficulties. A qualitative descriptive approach was considered appropriate because it allows for in-depth exploration of lived experiences and subjective interpretations, particularly when the aim is to capture the richness of participants' narratives rather than to test hypotheses or establish causality (Creswell & Poth, 2018). Within science education research, such an approach is often applied to studies focusing on teachers' practices, perceptions, and challenges in implementing instructional strategies, as it enables researchers to analyze context-specific accounts that quantitative measures might overlook (Merriam & Tisdell, 2016). In the present study, this design provided the flexibility to understand how teachers conceptualize abstract phenomena such as magnetism and how they perceive students' persistent learning difficulties.

Sampling was conducted purposively in order to recruit participants who could provide the most relevant and comprehensive insights into the phenomenon under study. Purposive sampling is widely recognized in qualitative research as a strategy that ensures the selection of information-rich cases, especially when the study seeks to elucidate specific experiences or expertise (Patton, 2015). In this study, the inclusion criteria were that participants must (1) have direct teaching experience with magnetism at the high school level, (2) be willing to engage in detailed interviews regarding their practices and challenges, and (3) be capable of articulating students' learning difficulties based on classroom experience. Following these criteria, three physics teachers from different regions in Indonesia — Java, Sulawesi, and Sumatra — were recruited. This geographic diversity was intended to capture variation in teaching contexts while also identifying potential commonalities across settings. Each teacher held a bachelor's degree in educational physics and had between four and seven years of teaching experience. Table 1 summarizes the demographic and professional characteristics of the participants.

Table 1. Participants' information

No	Experience	Education	Location	Teaching Method
1	4 years	Bachelor of educational physics	Java	Teacher-centered lecturing with classroom discussion; frequent use of digital instructional materials such as images and videos
2	7 years	Bachelor of educational physics	Sulawesi	Student-oriented approach using digital materials from educational agencies
3	5 years	Bachelor of educational physics	Sumatra	Student-oriented approach with emphasis on peer learning in the classroom

Data collection was conducted through semi-structured interviews, which are particularly suitable for eliciting detailed personal accounts while allowing for flexibility to probe emerging themes (Kvale & Brinkmann, 2015). The interviews focused on two key areas: (1) the challenges encountered in teaching magnetism and (2) students' difficulties in understanding magnetic concepts from the teachers' perspective. The interview protocol consisted of guiding questions designed to elicit narratives while also allowing for adaptation based on participants' responses. For instance, when a teacher highlighted difficulties with the right-hand rule, follow-up questions were posed to clarify how such challenges manifested in classroom practice and how students responded to them. Each interview lasted approximately 60–90 minutes, was audio recorded with consent, and was subsequently transcribed verbatim. The choice of semi-structured interviews ensured both comparability across participants and openness to unanticipated but relevant insights.

The data analysis employed a thematic approach, which is widely recommended for qualitative studies seeking to identify recurring patterns across narratives (Braun & Clarke, 2006). The process began with familiarization through repeated reading of transcripts, followed by initial coding of meaningful segments related to the research focus. Codes were then grouped into candidate themes that represented broader categories of meaning, such as "limitations of instructional media," "student difficulties in visualizing vector relationships," and "challenges in applying the right-hand rule." Themes were reviewed and refined iteratively to ensure coherence and distinctiveness before being finalized into an interpretative framework. To enhance the credibility of the findings, the analysis was supported by illustrative quotations directly extracted from the participants' accounts, thereby grounding interpretations in the data itself.

To strengthen the validity of the research, methodological triangulation was employed. This involved comparing interview data with instructional materials and media actually used by teachers, such as classroom slides, images, and videos. Triangulation is acknowledged in qualitative research as a means to corroborate findings by drawing on multiple sources of evidence, thus reducing the risk of bias or overreliance on self-reported data (Denzin, 2012). Furthermore, researcher reflexivity was practiced throughout the study by maintaining analytic memos that documented decision-making processes, reflected on coding, and identified potential researcher assumptions. Reflexivity in qualitative research is crucial for ensuring transparency and accountability in the interpretive process (Lincoln & Guba, 1985).

Ethical considerations were carefully addressed to protect participants' rights and maintain the integrity of the research. Before participation, teachers were provided with information about the study's objectives, procedures, and their right to withdraw at any point without consequence. Written informed consent was obtained, and pseudonyms were used to maintain confidentiality. Ethical guidelines in educational research emphasize that such safeguards are essential not only for protecting participants but also for enhancing the trustworthiness and credibility of the findings (BERA, 2018).

III. RESULTS AND DISCUSSION

The analysis of the interviews with three high school physics teachers revealed two overarching themes: (1) the instructional challenges faced by teachers in presenting magnetism, and (2) the conceptual difficulties observed among students in learning this topic. These themes highlight the interdependence between teachers' pedagogical practices and students' cognitive struggles, offering a comprehensive account of the complexities involved in teaching and learning magnetism.

3.1 Instructional challenges in teaching magnetism

All participating teachers reported persistent difficulties in explaining magnetic phenomena due to limitations of available instructional media. Teacher 1, for instance, noted that conventional classroom resources such as static images or videos could only partially depict magnetic field lines and failed to capture their three-dimensional orientation. As the teacher emphasized, "*We usually use pictures and videos, but students often cannot imagine the actual direction of the magnetic field*." This observation was echoed by Teacher 2, who highlighted the inadequacy of simple demonstrations, such as sprinkling iron filings around a bar magnet, in explaining the directional aspects of the field. Although such activities successfully illustrate the general pattern of magnetic lines, they do not convey vector directionality, which is crucial for understanding forces on moving charges or current-carrying wires.

Furthermore, the lack of interactive media was identified as a significant obstacle to promoting student engagement. Teacher 3 explained that while simulation tools were occasionally available, they tended to be static or oversimplified, and thus insufficient to support deep visualization of vector relationships. The reliance on conventional explanations, such as hand gestures or chalkboard sketches, often left students confused and dependent on rote memorization rather than conceptual reasoning. These testimonies underline the importance of instructional media that can dynamically represent vector directions and spatial relationships, thereby enabling students to construct accurate mental models of magnetism.

3.2 Students' conceptual difficulties in magnetism

From the teachers' perspectives, students frequently struggled with the abstraction and spatial reasoning required to master magnetism. One of the most common challenges reported was in applying the RHR. According to Teacher 2, "*Many students can state the rule, but when asked to apply it to a moving charge or current-carrying wire, they are unsure about which direction corresponds to the magnetic field and which to the force*." This suggests that while procedural recall of the rule is relatively straightforward, its application in varied contexts remains a persistent barrier.

Another difficulty lies in visualizing three-dimensional relationships between vectors of velocity, magnetic field, and force. Teacher 1 observed that "*students often confuse whether the thumb should represent velocity or current, and they cannot correctly orient their hands to match the diagram*." This difficulty is particularly pronounced when students encounter problems that deviate from textbook examples, indicating a reliance on memorization rather than genuine conceptual understanding. Moreover, Teacher 3 reported that students frequently conflated the rules governing magnetic fields around current-carrying conductors with those determining forces on moving charges, leading to systematic errors in problem-solving.

3. Integration of teachers' and students' challenges

A critical finding of this study is the overlap between teachers' instructional challenges and students' conceptual struggles. The inability of existing teaching media to accurately depict vector orientations directly contributes to students' confusion in applying the right-hand rule and visualizing three-dimensional interactions. The teachers unanimously agreed that more interactive and spatially explicit tools are required to bridge this gap. For example, simulations capable of showing real-time manipulation of charges, fields, and forces were described as potentially transformative for students' understanding. At the same time, the teachers emphasized that simply introducing new media would not suffice. Teacher 2 emphasized the importance of guided practice and scaffolding: "*Even if students use interactive simulations, they still need structured guidance to connect what they see with the underlying principles.*" This indicates that effective interventions must combine technological innovation with deliberate pedagogical design to ensure meaningful learning.

The findings of this study confirm and extend previous research on the persistent difficulties in teaching and learning magnetism at the secondary level. As highlighted in the results, teachers reported substantial challenges in conveying magnetic concepts due to limitations of instructional media. At the same time, students were observed to struggle with spatial visualization, particularly in applying the RHR. These outcomes resonate with earlier work by Klein et al. (2021) and Malgieri et al. (2021), who demonstrated that the abstraction of three-dimensional vector interactions in magnetism constitutes one of the most common barriers to conceptual understanding in physics education. The present study adds to this body of knowledge by situating these challenges within teachers' lived experiences, thereby providing a practical perspective on how instructional constraints exacerbate student misconceptions.

The difficulty in applying the RHR observed among students aligns with research indicating that spatial reasoning is a critical but often underdeveloped competency in physics learning (Han et al., 2021; Karadağ & Ünlü Yavaş, 2021). While students are often able to recite the rule, their inability to apply it across diverse contexts reflects reliance on procedural memorization rather than conceptual integration, a pattern that has been consistently documented in prior studies (Kähkönen et al., 2020; Kaliampos et al., 2021). Inadequate instructional representations appear to intensify this problem, as students are not provided with sufficient opportunities to manipulate vector relationships dynamically. This supports the assertion by Stepanović et al. (2019) and Andriani et al. (2022) that meaningful engagement with vector operations and three-dimensional reasoning is indispensable for fostering genuine understanding of electromagnetic phenomena.

Teachers' testimonies regarding the inadequacy of static media reinforce the argument that traditional demonstrations, while valuable for illustrating basic patterns of magnetic fields, are insufficient for teaching directional and vectorial aspects (Karadağ & Ünlü Yavaş, 2021; Tairab et al., 2020). For example, the common use of iron filings to visualize field lines does not address students' confusion about directionality, a limitation also emphasized by Kaliampos et al. (2021). The convergence of teacher reports in this study with prior evidence underscores the need to move beyond conventional demonstrations and incorporate tools that can explicitly link abstract representations to tangible experiences.

Recent advances in digital and interactive technologies offer promising pathways to address these instructional gaps. Prior research has shown that simulations, augmented reality (AR), and blended learning environments can enhance conceptual understanding by providing students with opportunities to interact with and manipulate abstract phenomena (Batdi & Talan, 2019; Garzón & Acevedo, 2019; Silva et al., 2023; Syskowski et al., 2024; Taha & Hu, 2023). The current findings support this trajectory by demonstrating that teachers themselves recognize the potential of such tools to alleviate visualization challenges. However, as noted by Malgieri et al. (2021), reliance on digital tools without pedagogical scaffolding risks producing superficial comprehension. This study's findings echo that concern, as teachers stressed the importance of structured guidance to help students connect simulation outputs with the underlying physical principles. Such an integrated approach aligns with the recommendations of Prahani et al. (2022) and Letina and Vasilj (2021), who argue that blended learning models that combine traditional experimentation with interactive simulations are particularly effective in building both conceptual and procedural knowledge.

Another important implication of this study is the recognition that teachers' challenges and students' difficulties are not isolated phenomena but are intertwined in ways that influence learning outcomes. The lack of adequate instructional media not only restricts teachers' ability to represent magnetic concepts but also directly contributes to the persistence of student misconceptions, such as confusion over the RHR or conflation of field rules for wires and moving charges. This interconnection reinforces the call by Chen (2019) and Han et al. (2021) for instructional design that explicitly integrates teacher support with student-centered learning activities (Bacaro, 2019). Addressing student difficulties, therefore, requires not only improved learning resources but also enhanced professional development opportunities for teachers, equipping them with the strategies to use interactive media effectively in classroom contexts.

The study also highlights a gap in the existing literature regarding teachers' perspectives. While much research has focused on diagnosing students' misconceptions in magnetism (Munfarikha et al., 2018; Silviani et al., 2020; Ürek & Çoramık, 2021; Guerra-Reyes et al., 2024), comparatively fewer studies have systematically investigated how teachers experience and interpret these difficulties. By foregrounding teachers' voices, this study offers practical insights into the realities of classroom instruction, including the constraints of resource availability and the pedagogical adaptations that teachers employ. These findings contribute to filling the gap identified by Kaliampos et al. (2021), who emphasized the need for more teacher-centered perspectives in understanding the dynamics of physics education.

From a broader educational standpoint, the results suggest that addressing persistent challenges in magnetism requires a dual focus on cognitive and structural dimensions. On the cognitive side, students require targeted interventions that strengthen spatial reasoning and vector understanding, such as guided practice with dynamic visualizations. On the structural side, teachers need access to instructional resources that can accurately represent three-dimensional phenomena, along with professional development to integrate these tools into their practice effectively. This holistic approach aligns with the vision articulated by Hoffmann and Moldwin (2022) and Yalçin and Sadik (2024), who argue that science education must bridge disciplinary content with pedagogical innovation to prepare students for technological and scientific literacy.

IV. CONCLUSION AND SUGGESTION

This study examined the challenges faced by high school physics teachers in teaching magnetism and their perspectives on students' conceptual difficulties. The findings revealed two major insights. First, teachers consistently reported that instructional media available in classrooms were insufficient for accurately depicting three-dimensional vector relationships, thereby limiting their ability to explain complex phenomena such as the direction of magnetic fields and forces. Second, students were found to struggle significantly with spatial reasoning, particularly in applying the right-hand rule, distinguishing between the rules for current-carrying wires and moving charges, and constructing transferable conceptual understanding. These intertwined challenges underscore the critical need for instructional strategies that combine conceptual clarity with interactive, spatially explicit media to enhance learning outcomes in magnetism.

Despite these contributions, the study has several limitations. The analysis was based on interviews with only three teachers, which, while providing valuable depth, may not capture the full diversity of experiences across different educational settings. Additionally, the reliance on teacher perspectives means that students' voices were not directly represented in the data. Future research should therefore expand the sample size, include student participants, and integrate classroom observations to provide a more comprehensive account of the teaching and learning of magnetism. Nevertheless, by foregrounding teachers' perspectives, this study makes an important contribution to the field of physics education. It highlights the structural and cognitive challenges that must be addressed through innovative instructional media, targeted pedagogical support, and professional development for teachers. In doing so, it offers both theoretical and practical insights into how persistent difficulties in magnetism education can be more effectively mitigated in secondary school contexts.

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