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ORIGINAL RESEARCH PAPER

Enhancing Conceptual Understanding in Magnetism through AI-Powered Tools: A Mixed-Methods Study with High School Students

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ABSTRACT

This research examines the influence of artificial intelligence (AI)-enabled instruments on comprehension, engagement, and retention of knowledge within high school physics education, particularly emphasizing the topic of magnetism. A mixed-methods methodology was utilized, merging a validated questionnaire distributed to 100 eleventh-grade pupils with qualitative analyses of open-ended responses alongside the practical application of selected AI instruments. The intervention comprised the employment of AI chatbots (e.g., ChatGPT), interactive simulations (PhET, Mozaik), concept mapping (Mindomo), and AI-generated educational music (Suno.ai). Quantitative findings demonstrated a significant consensus (78–85%) among students regarding perceived enhancements in understanding and engagement. Qualitative assessment indicated that chatbots and simulations were especially efficacious in elucidating misconceptions and facilitating the visualization of abstract concepts. A theoretical framework grounded in cognitive load theory and principles of multimedia learning is incorporated to elucidate the findings. Notwithstanding limitations pertaining to generalizability and access to technology, the research posits that a deliberate integration of AI tools can augment student-centered learning within the domain of physics. Suggestions for educators and avenues for future research are elaborated upon.

Keywords:
Physics education, magnetism, artificial intelligence, cognitive load theory, multimedia learning, mixed methods

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1. INTRODUCTION

Magnetism is a conceptually challenging topic in high school physics, often associated with persistent misconceptions such as the belief that all metals are magnetic or confusion about field lines and forces on moving charges (Singh, 2005; Maloney et al., 2001). Traditional teaching methods, while foundational, may not sufficiently address these conceptual barriers, particularly in promoting deep understanding and long-term retention.

Recent advances in artificial intelligence (AI), particularly in natural language processing and adaptive learning systems, offer new opportunities to support physics education. Unlike general educational technologies, true AI tools—such as large language models (LLMs) and intelligent tutoring systems—can provide personalized feedback, real-time Q&A, and adaptive scaffolding, aligning with principles of constructivist and student-centered learning [1, 2].

While virtual labs like PhET have been widely studied in physics education research (Wieman et al., 2008), the integration of generative AI tools (e.g., chatbots, AI music generators) in high school magnetism instruction remains underexplored. This study addresses this gap by examining how a combination of AI-powered tools influences students' conceptual understanding, engagement, and retention. It also explores the pedagogical mechanisms through which these tools operate, using cognitive load theory (Sweller, 1988) [3] and Mayer's multimedia learning theory (2009) [4] as analytical frameworks.

The research question guiding this study is:

How do AI-powered tools influence students' conceptual understanding, engagement, and retention in high school magnetism education?

1.1 Theoretical Framework

This study is grounded in two well-established theories of learning: Cognitive Load Theory (CLT) (Sweller, 1988) and Mayer's Cognitive Theory of Multimedia Learning (2009).

CLT posits that learners have limited working memory capacity, and effective instruction should minimize extraneous load while supporting germane load. AI tools such as chatbots and simulations can reduce cognitive load by providing just-in-time explanations, visualizing abstract concepts, and offering immediate feedback, thus allowing students to focus on schema construction.

Mayer's theory emphasizes that people learn better from words and pictures than from words alone, especially when design principles such as coherence, signaling, and personalization are applied. AI-generated content—such as narrated simulations, concept maps, and educational music—can be designed to align with these principles, enhancing dual-channel processing and meaningful learning.

Furthermore, AI chatbots can function as scaffolding agents (Vygotsky, 1978) [5], providing adaptive support that fades as student competence increases. This dynamic interaction supports a constructivist approach to learning, where students actively build knowledge through dialogue and exploration [6-10].

2. METHODOLOGY

2.1. Research Design

A mixed-methods explanatory sequential design was employed. First, quantitative data were collected via an online questionnaire to assess students' perceptions of AI tools. This was followed by qualitative analysis of open-ended responses to explore underlying reasons and experiences.

2.2. Participants

One hundred eleventh-grade students (ages 16–17) from three physics classes at a public high school in Iran participated voluntarily. The sample included 58 female and 42 male students. All had prior exposure to magnetism in their curriculum.

2.3. Intervention and Tools

Students were introduced to five AI-powered tools over a one-week period:

- ChatGPT: For Q&A on magnetism concepts.
- PhET & Mozaik: For interactive simulations of magnetic fields and induction. To illustrate the concept of magnetic fields, we utilized the PhET Interactive Simulations platform, which provides an interactive environment for visualizing magnetic phenomena. As depicted in Figure. 1, the simulation shows magnetic field lines around a bar magnet, with a compass needle aligning itself along these lines to demonstrate the direction and strength of the field at various points.

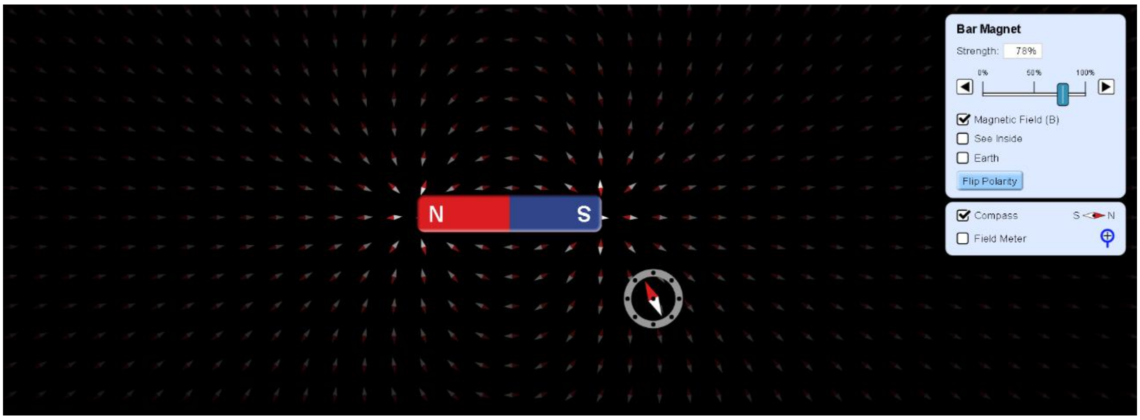

Figure 1. Visualization of magnetic field lines around a bar magnet using PhET Interactive Simulations. The compass needle aligns with the magnetic field, demonstrating the direction and strength of the field at different points.

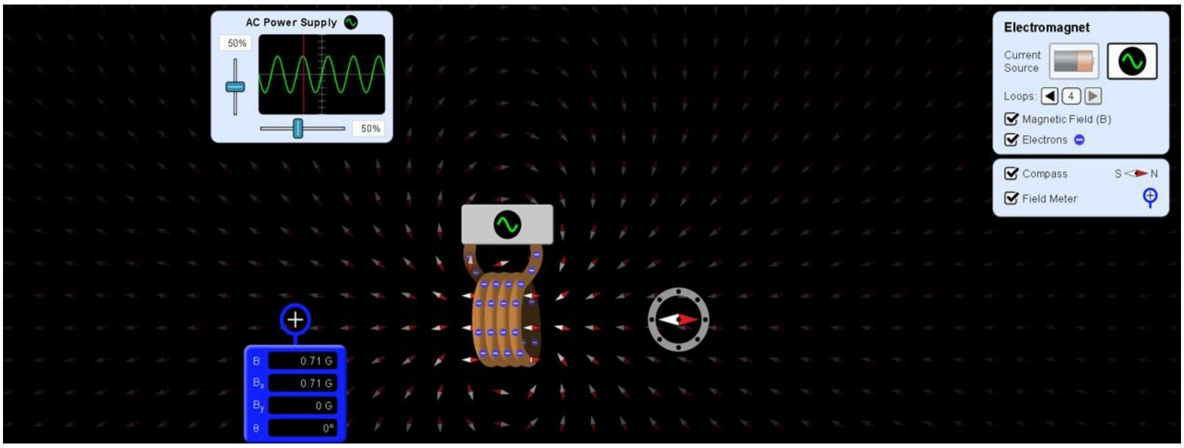

Figure. 2 Faraday's experiment in PhET

As shown in Figure. 2, interactive simulations like those provided by PhET allow students to visualize complex phenomena such as electromagnetic induction. The simulation demonstrates how an alternating current (AC) generates a magnetic field around an electromagnet, with tools like the compass and field meter providing real-time feedback on field strength and direction. This hands-on approach enhances conceptual understanding and engagement, as evidenced by student responses in our study.

As part of the AI-powered tools used in this study, interactive digital activities were employed to reinforce key concepts. For instance, Figure 3 shows a matching activity where students classified materials into ferromagnetic, diamagnetic, and paramagnetic categories. The task involved matching materials such as platinum, lead, and iron with their corresponding magnetic properties. Such interactive exercises were found to significantly improve student engagement and conceptual understanding.

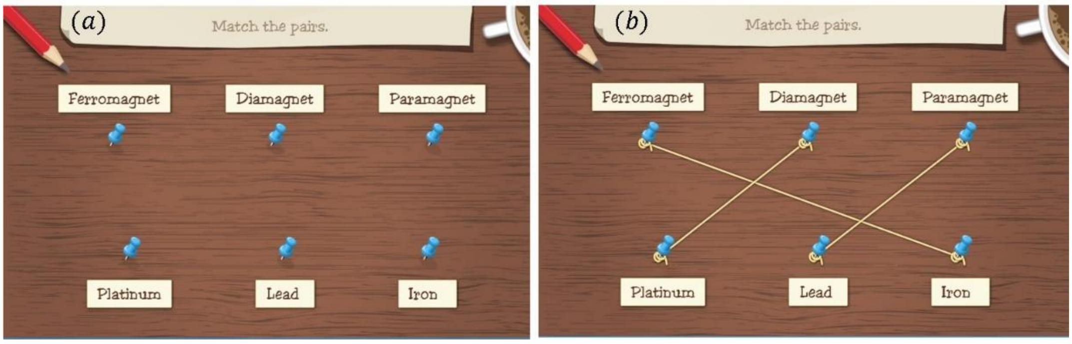

Figure 3. Interactive Matching Activity for Classifying Magnetic Materials; Part (a) showing the initial setup where students are asked to match materials such as platinum, lead, and iron with their corresponding magnetic properties. Part (b) displaying the correct answers.

- Mindomo: For creating concept maps of magnetism topics. As shown in Figure. 4, magnetic materials can be classified into three main categories: ferromagnetic, paramagnetic, and diamagnetic

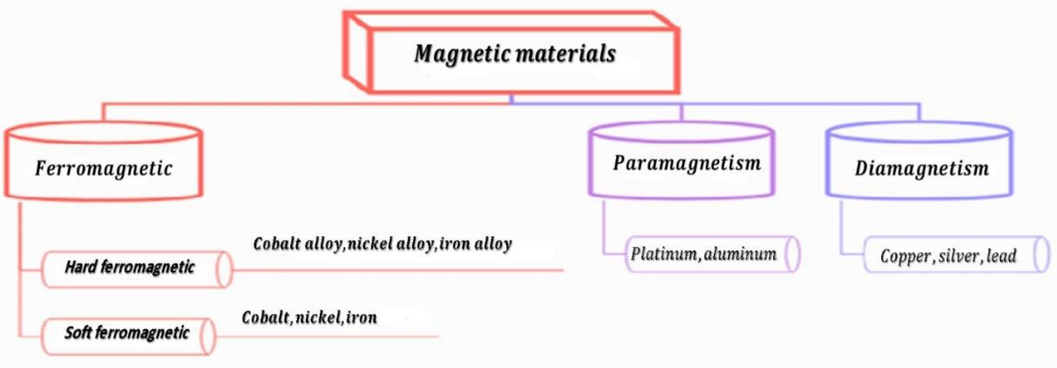

Figure 4. Classification of Magnetic Materials

This figure illustrates the classification of magnetic materials based on their response to external magnetic fields. Ferromagnetic materials, such as cobalt alloys, nickel alloys, and iron alloys, are further divided into hard ferromagnets (e.g., cobalt alloy) and soft ferromagnets (e.g., pure cobalt). Paramagnetic materials, including platinum and aluminum, show a weak attraction to magnetic fields, while diamagnetic materials like copper, silver, and lead exhibit a slight repulsion. This categorization is fundamental in understanding the behavior of materials in magnetic fields.

- Suno.ai: For generating educational music on key principles.

Each tool was demonstrated, and students were given guided activities (e.g., "Use ChatGPT to explain why aluminum is not magnetic").

2.4. Data Collection

An 8-item Likert-scale questionnaire (5-point: Strongly Disagree to Strongly Agree) was administered online. Items addressed understanding, engagement, retention, and usability. An open-ended question asked: *"Which tool impacted your learning the most, and why?"*

The questionnaire was pilot-tested with 10 students and revised for clarity. Content validity was confirmed by two physics education experts. Cronbach's alpha was calculated to assess internal consistency ($\alpha = 0.82$), indicating acceptable reliability.

2.5. Data Analysis

Quantitative data were analyzed using descriptive statistics (frequencies, percentages). Qualitative responses were analyzed using thematic analysis (Braun & Clarke, 2006) to identify recurring patterns (e.g., "visualization," "immediate feedback," "engagement through music").

Appendix A are pie charts displaying responses to each of the 8 main questions. Question 1: Using AI tools increased my understanding of magnetism.
Question 2: Interactive simulations like PhET made concepts more tangible.
Question 3: Multimedia tools like Mozaik aided visual learning.
Question 4: Educational chatbots like ChatGPT provided quick, accurate answers.
Question 5: Creating concept maps with Mindomo helped organize ideas.
Question 6: Educational music (e.g., Suno.ai) improved memory retention.
Question 7: These tools made learning more engaging and personalized.
Question 8: I would prefer using AI tools if studying this topic again.

3. RESULTS AND DISCUSSION

3.1. Quantitative Findings

As shown in Figure 5, 82% of students agreed or strongly agreed that AI tools improved their understanding of magnetism. PhET and ChatGPT received the highest agreement (85% and 83%, respectively). Suno.ai and Mindomo also showed strong positive responses (76% and 74%). Over 90% reported increased engagement (Table. 1).

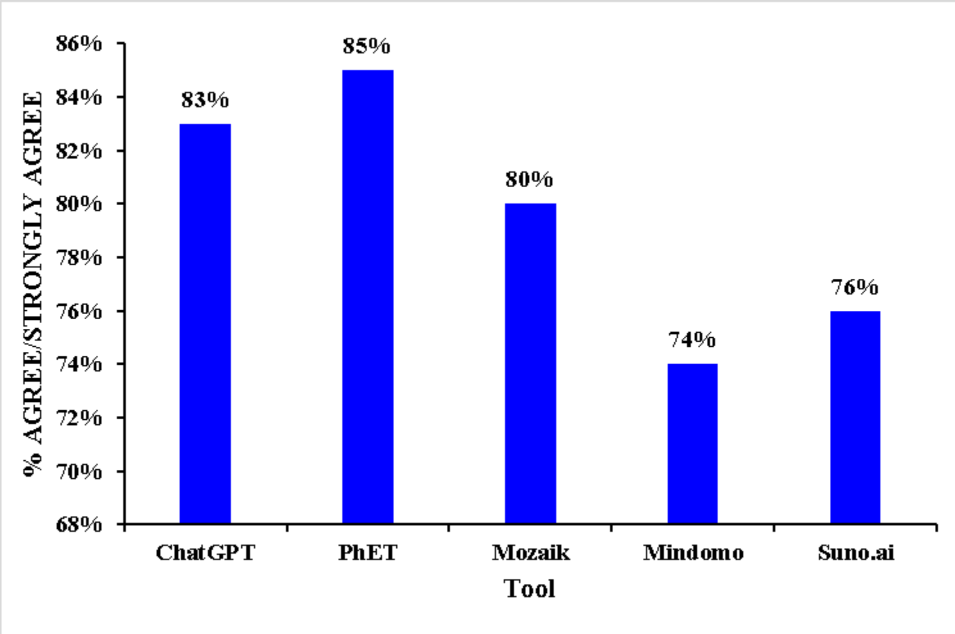

Figure 5. Student agreement on the impact of AI tools on understanding magnetism (N = 100).

Table 1. Percentage of students agreeing on the effectiveness of each AI tool.

TOOL	% AGREE/STRONGLY AGREE
ChatGPT	83%
PhET	85%
Mozaik	80%
Mindomo	74%
Suno.ai	76%

3.2. Qualitative Findings

Thematic analysis of open-ended responses revealed three main themes:

1. Conceptual Clarity: Students appreciated ChatGPT's ability to explain misconceptions (e.g., *"I finally understood why not all metals are magnetic"*).
2. Visualization and Interaction: PhET and Mozaik were praised for making invisible fields "visible" and "interactive."
3. Emotional Engagement: Many noted that music (Suno.ai) made learning "fun" and "memorable," especially for rote concepts like right-hand rules.

"The song helped me remember the right-hand rule without even trying. I was humming it during the test!"— Student 47

The below table compares tools like PhET, Mozaik, ChatGPT, Suno.ai, and Mindomo based on interactivity, content diversity, ease of use, learning impact, question-answering, simulation, and content generation capabilities.

Table. 2 Comparison of AI Tools in Teaching Magnetism Concepts

Feature	PhET	Mozaik	ChatGPT	Suno.ai	Mindomo
Interactivity	Very high	High	Medium	Low	Top
Content diversity	Scientific simulation	Multimedia (video, image)	Textual	Audio	Textual-visual (concept maps)
Ease of use	Easy	Average	Very easy	Average	Easy
Impact on learning	Strengthens conceptual understanding	Increases visual appeal	Facilitates understanding of concepts	Increases retention	Mental order and connection of concepts
Answering questions	No	No	Yes	No	No
Simulation	Yes	Limited	No	No	No
Possibility of content production	No	Yes	Yes	Yes	Yes (concept map)

4. Discussion

The findings suggest that AI tools, particularly chatbots and simulations, can play a meaningful role in enhancing magnetism education by reducing cognitive load, providing immediate feedback, and increasing engagement. These results align with Mayer's (2009) multimedia principles and Sweller's (1988) cognitive load theory, supporting the idea that well-designed AI tools can support dual coding and schema formation.

The high impact of educational music is noteworthy, as it reflects the role of affective and rhythmic processing in memory retention (Jäncke & Sandmann, 2010). However, this may be more effective for factual recall than deep conceptual understanding.

Our results are consistent with prior studies on virtual labs (Wieman et al., 2008), but extend them by incorporating generative AI tools like chatbots and AI music generators, which have not been systematically studied in high school physics contexts.

Limitations

- The sample is limited to one school and grade level.
- No pre/post conceptual test was administered.
- Self-reported data may be subject to bias.
- Internet access and device availability varied among students.

Implications for Practice

- Teachers should consider integrating AI chatbots for Q&A and misconception correction.
- Simulations should be used to visualize abstract concepts.
- Creative tools like AI music can enhance motivation and retention.

Future Research

- Longitudinal studies with control groups.
- Integration of AI with standardized assessments (e.g., CSEM).
- Development of localized AI tools for non-English educational systems.

5. CONCLUSION

This study demonstrates that AI-powered tools can positively influence high school students' learning of magnetism when integrated thoughtfully. By aligning tool use with cognitive and multimedia learning theories, educators can enhance conceptual understanding, engagement, and retention. While challenges related to access and infrastructure remain, the pedagogical potential of AI in physics education is significant and warrants further exploration.

6. Recommendations

- Train physics teachers in the effective use of AI tools.
- Develop open-access AI platforms tailored to national curricula.
- Conduct larger-scale studies with control groups and conceptual assessments.
- Encourage interdisciplinary collaboration between physicists, educators, and AI developers.

7. Acknowledgments

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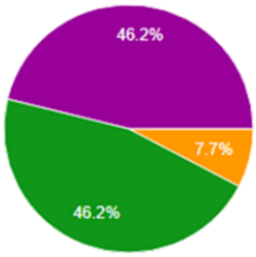
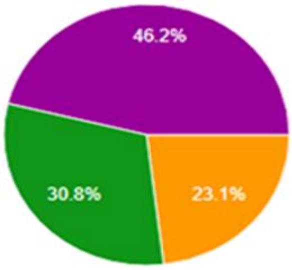
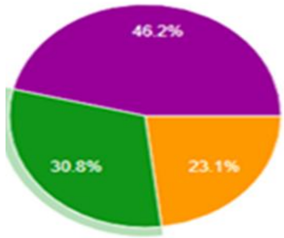
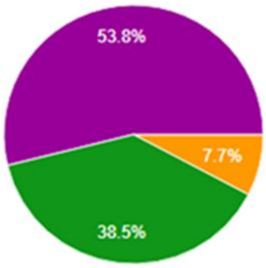
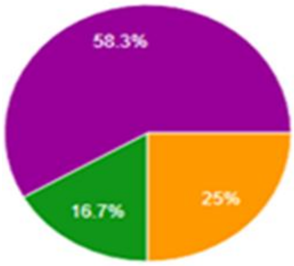
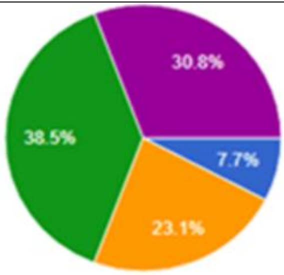
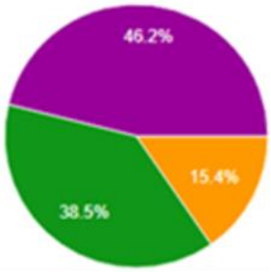
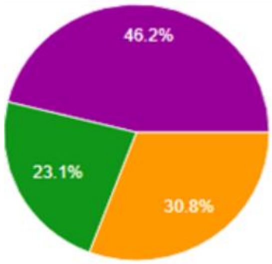
Appendix A:

Table A.1: Status of Responses to Questions

Strongly disagree: Blue color, **Disagree**: Red color, No **opinion**: Orange color, **Agree:** Green color, **Strongly agree:** Purple color		
		
Question 3	Question 2	Question 1
		
Question 6	Question 5	Question 4
		
	Question 8	Question7