Magnetism in Everyday Technology: An Integrative Review of Principles, Devices, and Educational Implications

Elsiana Velsi[1], Tya Ratu Elizar[2]
Universitas Indraprasta PGRI[12]
E-mail: elsianavelsi02@gmail.com

Abstract
The advancement of science and technology has significantly transformed human life, and among the most essential phenomena underlying these developments is magnetism, which has long served as both a theoretical foundation and a practical enabler of innovation. This study employed a descriptive qualitative design through an extensive literature review of academic books, peer-reviewed journals, and reputable online resources to analyze the principles of magnetism and their applications in daily life. The findings reveal that magnetic fields are widely utilized in household devices such as refrigerators, electric bells, and loudspeakers, as well as in advanced technologies including electric motors, telecommunication systems, and medical imaging. The results further demonstrate that magnetism is not only central to technological innovation but also provides significant educational value by linking abstract concepts with real-world experiences, thereby enhancing conceptual understanding and student engagement. Comparative analysis with previous studies confirmed the reliability of these findings while highlighting the novelty of this research in synthesizing historical, theoretical, and practical dimensions into a single holistic narrative. The study implies that integrating magnetism into science curricula and leveraging its practical relevance can strengthen science literacy and foster innovation, while also underscoring the potential of magnet-based systems for advancing sustainable energy and engineering solutions.

Keywords: Daily Life; Education; Electromagnetism; Magnetism; Technology.

INTRODUCTION

The rapid advance of science and technology has reshaped everyday life by converting foundational physical insights into scalable devices and infrastructures. Within this transformation, magnetism stands out as both an explanatory construct and a design substrate: improvements in soft-magnetic materials have directly enabled lighter, smaller, and more efficient power electronics and electro-mechanical systems, accelerating electrification across sectors (Schmool, 2022; Ubaidillah et al., 2022; Wang et al., 2022). In practical energy conversion, the interaction of current-carrying coils with engineered magnetic circuits underpins torque production in modern machines, where design reviews document how magnetic topology, material loss modeling, and multi-objective optimization jointly drive efficiency and reliability especially in permanent-magnet synchronous systems for wind and e-mobility (Mörée & Leijon, 2023; Silveyra et al., 2018; Yee Heng et al., 2022). Beyond power, magnetism energizes information and communication technologies: spintronics leverages spin-dependent transport for non-volatile memory and logic, while electromagnetic field engineering at mmWave frequencies (e.g., compact 5G MIMO arrays) demonstrates how precise control of fields yields spectral efficiency and device miniaturization (Hirohata et al., 2020; Megahed et al., 2023). Parallel progress in magnetically coupled wireless power corroborates magnetism's role in convenient, contactless energy delivery for consumer devices and e-mobility charging, with resonance-coupled links improving transfer efficiency and misalignment tolerance (Ali et al., 2021). In medicine, the renewed momentum of low-field, permanent-magnet MRI illustrates how magnetic hardware innovations, paired with reconstruction advances, can broaden access and reduce siting and cryogen constraints while

maintaining clinically useful performance (Arnold et al., 2023; de Vos et al., 2021; Hori et al., 2021). Taken together, these developments affirm that magnetism long recognized and systematically studied now functions as a pervasive engine of modern convenience, efficiency, and innovation, linking ancient observations to today's communication networks, renewable-energy systems, transport platforms, and diagnostic tools (Hirohata et al., 2020; Renuka Balakrishna & James, 2022; Silveyra et al., 2018).

Magnetism can be broadly defined as the physical phenomenon in which materials exert forces of attraction or repulsion due to the motion and intrinsic angular momentum (spin) of charged particles, primarily electrons. At the macroscopic level this behavior is represented by magnetic fields vector fields that, although invisible, govern the interaction between matter and energy through relations such as $B = \mu_0(H + M)$ and the Lorentz force acting on moving charges. The diverse responses of materials arise from how atomic magnetic moments align under an applied field: diamagnetic substances develop weak, field-opposing currents and thus negative susceptibility; paramagnetic materials possess unpaired electrons whose moments align statistically with the field, yielding small positive susceptibility that diminishes with temperature; and ferromagnetic materials exhibit strong, cooperative alignment of moments within domains, producing large, nonlinear susceptibility and, below a characteristic Curie temperature, spontaneous magnetization even without an external field. In ferromagnets, the motion of domain walls and rotation of moments underlies hysteresis, characterized by coercivity and remanence, which distinguishes soft magnetic materials (low losses, easy magnetization) from hard magnetic materials (high coercivity for permanent magnets). Anisotropy, microstructure, and defects further shape the field response, while engineered composites and thin films tailor permeability, losses, and frequency performance. Collectively, this taxonomy and its underlying quantum statistical origins make magnetism central to both theory linking microscopic moments to Maxwellian fields and application, spanning sensors, actuators, data storage, power conversion, and imaging (Li & Yan, 2020; Sezer et al., 2021; Wei et al., 2022). Furthermore, electromagnetism first systematized through Faraday's discovery of induction and Maxwell's unification of electricity, magnetism, and light—remains a cornerstone of modern physics and engineering because it supplies the conceptual and predictive framework used to control field–matter interactions from direct current to terahertz frequencies. It explains how changing electric and magnetic fields generate one another and propagate as electromagnetic waves, and how those fields behave at interfaces and within real materials characterized by properties such as permittivity, permeability, conductivity, anisotropy, dispersion, and hysteresis. On this foundation, electric machines and power converters harness induction to produce torque and transfer energy, while advanced control and high-frequency switching deliver high efficiency and fast dynamics. In telecommunications, antennas, waveguides, and metasurfaces are designed by solving electromagnetic boundary problems to achieve beamforming, multiplexing, and reliable links across microwave and millimeter-wave bands. In data storage and information processing, engineered fields and magnetic materials enable recording heads, read/write transducers, and emerging spin-based memories that manipulate magnetization at nanoscales. The same principles underpin wireless power transfer, radar and remote sensing, medical imaging such as MRI, and electromagnetic compatibility. Across these domains, the Faraday–Maxwell framework guides modeling, optimization, and system integration, translating fundamental physics into robust, scalable technologies (Amineh, 2020; McCall & Nlebedim, 2021; Rodriguez-Vargas et al., 2023).

In everyday contexts, magnetism has become inseparable from human activity, embedding itself in objects and systems that people use from morning to night. In the home, permanent magnets provide tight seals on refrigerator doors and drive compact actuators and loudspeakers whose voice coils translate electrical signals into audible sound. Across consumer electronics, miniature vibration motors, magnetic sensors (such as Hall-effect and magnetoresistive devices), and brushless DC fans regulate haptics, position, and cooling with high reliability. In transportation and energy, permanent-magnet machines propel electric bicycles and vehicles, while generators in wind turbines convert rotational motion into electrical power with exceptional efficiency. In healthcare, magnetic resonance imaging (MRI) has transformed diagnostics by producing detailed,

non-invasive images of soft tissues, and magnetically guided instruments are increasingly used for targeted therapies and minimally invasive procedures. In the information sphere, magnetic recording has long enabled dense data storage in hard disk drives, and magnetically encoded stripes historically secured financial transactions on cards, complemented today by other electromagnetic identification methods. Even seemingly simple mechanisms electric bells, relays, telephone receivers, and door chimes still rely on magnetic fields to actuate motion, switch circuits, or convert between electrical and acoustic energy. Taken together, these diverse exemplars demonstrate how magnetism links fundamental understanding of matter with tangible gains in safety, comfort, efficiency, and access to modern services, underscoring its dual role as a scientific cornerstone and a practical engine of technological capability.

Previous studies have consistently highlighted the educational and technological significance of magnetism, particularly in its capacity to connect abstract theory with tangible application and thereby deepen learning. Work on solenoid design has established practical routes to highly homogeneous magnetic fields through tailored coil geometries, compensation windings, effective magnetic shielding, and stable drive electronics enabling reproducible classroom demonstrations and precision instruments alike. At the same time, biophysical investigations have clarified plausible pathways by which weak magnetic fields can interact with living systems, for example through the alignment of molecular moments, spin-dependent reaction kinetics, or magneto-mechanical coupling, providing authentic contexts for discussing the reach and limits of electromagnetic principles. In physics education, hands-on magnetic applications loudspeakers, electric motors, induction cookers, magnetic levitation, and simple electromagnetic relays serve as concrete anchors for core ideas such as field superposition, induction, energy conversion, and material response; when paired with interactive simulations and structured laboratory tasks, these activities promote conceptual change, transfer to novel situations, and sustained engagement. Taken together, this body of work positions magnetism as a uniquely integrative domain in which theory, experiment, and technology reinforce one another, offering both design heuristics (e.g., field-homogeneity targets, misalignment tolerances, loss minimization) and pedagogical strategies (e.g., project-based tasks, inquiry labs, blended virtual-physical experiments) that help learners connect fundamental electromagnetic laws to the devices they encounter every day (Alahmer et al., 2021; Gaeta et al., 2021; Sun, 2024). Other investigations have also emphasized electromagnetism in industrial and engineering contexts, including efforts to optimize the performance of electric motors, develop efficient energy transmission systems, and design advanced communication technologies. In electric machines, performance gains increasingly come from holistic co-design: rotor/stator topology tuning (magnet segmentation, skewing, slot–pole selection, axial- or interior-flux layouts), refined loss modeling for copper, hysteresis, and eddy currents, thermal path engineering for windings and magnets, and control strategies that coordinate torque production, ripple suppression, and flux-weakening across wide speed ranges. Manufacturability and reliability are addressed through tolerance-aware geometry, demagnetization margins, mechanical stress and sleeve integrity at high speed, and noise–vibration–harshness mitigation via harmonic shaping alongside sustainability goals such as rare-earth reduction and recyclability. In energy transmission, electromagnetism underpins both wired and wireless paradigms: at grid scale, high-efficiency transformers, HVDC corridors, and flexible AC transmission devices improve capacity and stability; at device and vehicle scale, magnetically coupled wireless power transfer balances efficiency, misalignment tolerance, electromagnetic compatibility, and safety through coil geometry, ferrite shielding, compensation networks, and adaptive control. Power-electronics advances (SiC/GaN switches, soft-switching converters, solid-state transformers) raise operating frequency and power density while maintaining power quality and meeting emissions limits. In communications, electromagnetic field control defines capability: antenna arrays and beamforming at microwave and millimeter-wave bands deliver directive links under mobility; metasurfaces and reconfigurable intelligent surfaces reshape propagation to extend coverage and suppress interference; and tightly integrated RF front-ends, filters, and packaging manage loss, coupling, and thermal constraints. At shorter ranges, near-field systems NFC, RFID, and magnetic-sensor networks use inductive or magnetoresistive coupling for identification, sensing, and low-power data exchange. Across these domains, the common thread is rigorous electromagnetic

modeling coupled with materials, thermal, mechanical, and control co-optimization, translating fundamental field principles into robust, scalable solutions for traction, grids, and high-throughput wireless connectivity. (Ali et al., 2021; Kim & You, 2022; Megahed et al., 2023).

Despite the extensive body of literature, significant gaps remain in research that explicitly integrates theoretical understanding of magnetism with its practical applications in everyday life, particularly within the context of science education. Much of the existing scholarship emphasizes either highly technical aspects of magnetism for specialized audiences or general overviews that lack systematic connections between concepts and daily experiences. Consequently, there is limited research that holistically synthesizes the historical, theoretical, and practical dimensions of magnetic phenomena to highlight their educational and technological implications in accessible formats. Addressing this gap is critical not only for advancing scientific knowledge but also for promoting science literacy among students and the general public.

The present study aims to bridge this gap by conducting a comprehensive literature-based analysis of the utilization of magnetic fields in daily life. Specifically, this research seeks to (a) examine the principles of magnetism from both theoretical and applied perspectives, (b) identify key examples of how magnetic fields are employed in technological devices that shape everyday experiences, and (c) evaluate the broader educational implications of integrating magnetism into science learning. By doing so, this study contributes to strengthening the connection between scientific theory and practical application, offering insights for both academic discourse and pedagogical innovation.

METHODS

This study employed a descriptive qualitative design using a literature review approach to examine the principles and applications of magnetic fields in daily life. Data collection relied exclusively on secondary sources, including peer-reviewed journal articles, academic textbooks, and reputable online publications relevant to magnetism and its utilization in technological and educational contexts. The selection of sources was conducted purposively to ensure both relevance and credibility, focusing on materials that provide theoretical explanations, empirical findings, and practical applications of magnetism. The data analysis process followed a thematic content analysis framework, in which key concepts and themes were identified, categorized, and synthesized to generate a comprehensive understanding of how magnetic phenomena are manifested in everyday technologies such as electric motors, telecommunication devices, household appliances, and educational tools. To ensure reliability, data triangulation was performed by cross-verifying findings across multiple sources, while validity was strengthened through the inclusion of diverse perspectives ranging from physics education research to applied engineering studies. Ethical considerations were also addressed by appropriately citing all sources in accordance with APA 7 standards, ensuring academic integrity and the avoidance of plagiarism. The methodological rigor of this study rests on its systematic procedure for identifying, analyzing, and synthesizing literature, thereby enabling a holistic exploration of magnetism as both a scientific principle and a practical resource for technological and pedagogical innovation.

RESULTS AND DISCUSSION

Magnetic fields demonstrably permeate everyday life and advanced technologies alike, functioning as both explanatory constructs in physics and enabling mechanisms in engineered systems. In energy conversion, contemporary motor research shows how interactions between current-carrying coils and structured magnetic circuits transform electrical energy into mechanical torque with high efficiency, quantified through full efficiency maps, torque speed envelopes, and constant-power ranges. Design-optimization of permanent-magnet machines now spans the entire stack: topology tuning (magnet shaping and segmentation, rotor skewing, slot–pole selection, fractional-slot concentrated windings, axial- and interior-flux layouts), targeted cogging-torque suppression (tooth notching, skew, optimum pole/slot combinations), and refined loss modeling that separates copper, hysteresis, and eddy-current components and links them to thermal paths and cooling strategies. Multiphysics finite-element analyses are coupled with reduced-order and system-level models to support multi-objective optimization across

efficiency, power density, cost, acoustic noise and vibration, demagnetization resilience, and fault tolerance. Material choices electrical steels versus amorphous laminations, soft-magnetic composites for 3D flux, and magnet chemistries from ferrite to NdFeB with temperature-dependent properties are evaluated alongside manufacturability factors such as tolerances, stacking, magnet placement, bonding, and rotor sleeve integrity at high speed. At the control and power-electronics layer, field-oriented and model-predictive strategies co-evolve with hardware to achieve maximum-torque-per-ampere and flux-weakening operation, suppress ripple, and maintain dynamic performance under voltage and current limits; SiC/GaN inverters raise switching frequencies and power density while meeting electromagnetic-compatibility targets. Reliability is addressed through tolerance-aware design, thermal cycling and mechanical stress analysis, and noise vibration harshness mitigation via force-harmonic shaping, all validated by hardware-in-the-loop testing and standardized characterization. Sustainability considerations rare-earth reduction, magnet recycling, and design for disassembly are increasingly embedded in the same optimization loop. Taken together, these studies confirm that performance, reliability, and manufacturability hinge on magnetic topology, material selection, and tightly integrated controls and power electronics, reinforcing the conclusion that electromagnetism is the operative bridge between physical law and practical motion conversion across traction, robotics, renewables, and precision mechatronics (Duan et al., 2021; Mociran & Topa, 2023; Park et al., 2023).

The claim that magnets are engines of innovation across communication and power infrastructure is likewise borne out by recent advances. In wireless communications, millimeter-wave 5G systems and reconfigurable intelligent surfaces (RIS) are explicitly electromagnetic: antenna arrays, metasurfaces, and wave-control strategies exploit field interactions to shape propagation, isolation, and spectral efficiency. At mmWave, higher path loss and blockage are countered by highly directive beams produced by dense arrays using hybrid analog–digital beamforming, phase-shifter networks, and lens or phased-array architectures that concentrate energy toward intended users while suppressing interference. Robust operation hinges on array calibration, mutual-coupling management, and isolation techniques (e.g., decoupling structures and electromagnetic band-gap surfaces), together with agile beam-management procedures initial access, tracking, and codebook design that sustain links under mobility and dynamic channels. Spectral efficiency is pushed further by massive MIMO and spatial multiplexing, but must be balanced against hardware realities such as finite phase resolution, RF-chain count, quantization noise, beam squint across wide bandwidths, and front-end insertion losses; packaging, thermal constraints, and co-integration with RFICs and filters also shape practical performance. RIS extends optimization from the transceiver to the environment itself: programmable meta-atoms impose controllable phase (and, in advanced designs, amplitude and polarization) so that reflections can be steered, focused, or diffused to fill coverage holes, enhance desired links, and mitigate inter-user interference. System-level gains rate coverage, reliability, and energy efficiency depend on aperture size and element count, discrete phase quantization, placement relative to base stations and users, and low-overhead control of the cascaded channel. Emerging variants such as transmissive or STAR-RIS enable simultaneous service on both sides of a panel, while space–time-modulated metasurfaces dynamically sculpt beams and suppress interference. Realizing these gains in practice requires fast channel acquisition and configuration (e.g., compressive estimation, element grouping), low-loss biasing networks that preserve passive efficiency, and cross-layer co-design so RIS states, beamforming weights, and scheduling evolve with traffic and mobility. Collectively, these hardware algorithm co-design advances show how precise electromagnetic control at surfaces and arrays translates into tangible improvements in coverage, isolation, and spectral efficiency without altering the underlying physical principles of wave propagation. (Alamzadeh et al., 2021; Megahed et al., 2023). In wireless power transfer (WPT), magnetically coupled resonant links have matured from laboratory prototypes to practical systems, with design reviews detailing coupling, misalignment tolerance, and efficiency trade-offs germane to consumer electronics and e-mobility (Ali et al., 2021; Laha et al., 2023).These trajectories confirm that electromagnetic field engineering undergirds both high-throughput communication and safe, contactless energy delivery.

Your emphasis on medical diagnostics is well supported by the resurgence of low-field MRI based on permanent magnets. State-of-the-art reviews and clinical studies document hardware software innovations (e.g., advanced reconstruction, optimized gradients, and novel magnet assemblies) that widen access, reduce cost, and enable point-of-care imaging while acknowledging SNR limits and use-case selection (Arnold et al., 2023; Hori et al., 2021). Technical reports further demonstrate viable permanent-magnet architectures around 50 mT, validating the feasibility of portable diagnostic scanners and aligning with your observation that magnetism's practical manifestations directly influence healthcare quality and reach (de Vos et al., 2021)

At the household and consumer level, magnets remain foundational in actuators and transducers refrigerator door seals, loudspeakers, vibration motors, and precision positioners where compact permanent-magnet assemblies deliver force and fidelity in constrained volumes. Market-level analyses quantify the ubiquity of NdFeB magnets across consumer electronics, corroborating their role as quiet enablers of daily experience (Heim & Vander Wal, 2023). Meanwhile, upstream research into generator and drivetrain design for renewables (e.g., permanent-magnet synchronous generators in wind) highlights magnetic materials and topologies as levers for sustainability through higher efficiency and reduced maintenance (Park et al., 2023; Xiao et al., 2022; Yee Heng et al., 2022).

On the materials and modeling side, contemporary reviews synthesize hysteresis modeling, loss mechanisms, and magnetic constitutive behavior, underscoring their indispensability for optimizing motors, transformers, memory devices, and spin-enabled electronics. These analyses refine classical hysteresis descriptions into predictive tools for digital design flows and efficient control strategies, providing an updated evidence base for your discussion of hysteresis-critical technologies (Mörée & Leijon, 2023). In parallel, the field-uniformity requirements you cite for solenoids and electromagnets are being advanced by algorithmic coil design and homogeneity optimization, which translate directly into more reliable instruments and sensors (Orosz et al., 2023; Yang et al., 2020).

Your pedagogical implications using tangible magnetic applications to elevate conceptual understanding are strongly echoed in recent education research. Controlled studies and multi-course case analyses show that virtual/remote laboratories, structured simulations (including PhET-style environments), and authentic project work in electromagnetism can improve conceptual gains, reduce achievement gaps, and support transfer from theory to practice when paired with active-learning designs (Banda & Nzabahimana, 2021; Filanovich & Povzner, 2021; Van den Beemt et al., 2023). These findings substantiate your recommendation that educators foreground everyday magnetism to demystify abstract formalisms and sustain engagement.

Taken together, these converging literatures reinforce the dual nature you articulate: magnetism is a cornerstone theoretical framework and simultaneously a design substrate for technologies that improve safety, convenience, and sustainability. The novelty of your study lies in integrating these dimensions materials and modeling, devices and systems, education and accessibility—into a cohesive narrative that is both scientifically rigorous and pedagogically actionable. Practically, the synthesis points to two high-value directions: (i) education that consistently contextualizes field concepts via authentic magnetic technologies, and (ii) continued innovation in magnet-based systems for renewable energy, transportation, and healthcare, where gains in efficiency, rare-earth stewardship, and portability carry system-level impact. Limitations remain: the present work is literature-based and thus sensitive to publication bias and scope gaps (e.g., fast-moving topics like quantum and nano-magnetism). Future work would benefit from empirical classroom interventions with robust assessments, as well as laboratory case studies that connect materials-level advances (e.g., hysteresis engineering) to device-level outcomes and user-level benefits.

CONCLUSION

This study concludes that magnetic fields constitute a fundamental scientific principle with wide-ranging implications for daily life, spanning from household applications such as refrigerators, electric bells, and loudspeakers to advanced technologies including electric motors, telecommunication systems, and medical imaging. Through a comprehensive literature-based synthesis, the research demonstrates how magnetism bridges theoretical physics with practical applications, thereby enhancing both technological innovation and educational relevance. The novelty of this work lies in its integrative perspective, which combines historical, theoretical, and practical dimensions of magnetism into a coherent narrative that underscores its centrality in human progress. The findings carry important implications for science education, suggesting that embedding real-world applications of magnetism in curricula can foster deeper conceptual understanding and student engagement, while also pointing to the necessity of continuous innovation in magnet-based technologies to address sustainability challenges in energy and engineering. Despite its reliance on secondary data, which limits empirical validation, this study contributes to the broader discourse on science literacy and interdisciplinary knowledge, and it calls for future research that integrates experimental approaches and explores emerging areas such as nanotechnology and quantum magnetism.

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