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Teaching Magnetism in Early and Primary Education through Technology-Enhanced Inquiry-Based Science Education STEM, Educational Robotics, and Artificial Intelligence as Mediational Approaches

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Abstract
In early physics education, magnetism is one of the most conceptually challenging topics since it is invisible, non-contact, and relational. As young learners approach magnetic phenomena with solid intuitive conceptions that resist change, magnetism is a paradigmatic illustration of how complicated scientific ideas can be meaningfully introduced in early childhood and primary education. Recent educational reforms stress STEM integration, educational robotics, and AI to innovate early scientific teaching. The literature is fragmented, with little theory-driven synthesis of how these approaches might be systematically connected to assisting conceptual learning. This article reviews Greek and international research on teaching magnetism using STEM pedagogy, educational robotics, and artificial intelligence in early childhood and primary education. Based on constructivism, conceptual transformation, sociocultural, and constructionist views, the research investigates each approach's epistemic affordances and proposes an integrated pedagogical model that aligns action, representation, and discourse around conceptual aims. The review emphasizes the effectiveness of design-based inquiry, embodied engagement, and adaptive scaffolding in reconstructing naïve concepts and fostering relational and mechanical understanding. This study contributes to physics education debates regarding how technology-enhanced learning environments might enable deep conceptual engagement in the early years by making magnetism a privileged case for integrated pedagogy.

Keywords: Magnetism, Early Childhood, Primary Education, STEM Education, Educational Robotics, Artificial Intelligence in Education

1. Introduction

Magnetism is one of the first physical phenomena infants discover that involves unseen forces, distant action, and relationship qualities. Magnetic interactions are different from many daily occurrences because learners must infer causal linkages from effects rather than directly observe them. In early childhood and elementary education, where children's reasoning is based on visual experience and daily language, this epistemic opacity makes magnetism an especially difficult conceptual area. Research consistently shows that young learners approach magnetism with powerful intuitive theories, often assuming that all metals are magnetic, that magnetism can be "used up," or that larger objects necessarily exert stronger magnetic effects. If not addressed, these theories often persist into later schooling. Physics education research views magnetism as a complex concept that requires controlled learning environments to facilitate conceptual transformation.

The early years are widely acknowledged as crucial for developing core scientific ideas, epistemic practices, and science attitudes. Physical phenomena in preschool and primary education impact what children know and how they perceive scientific explanation, evidence, and inquiry. Magnetism is unique within this framework. It is strongly linked to magnets, toys, and household things, but its processes are not visible. Because of its familiarity and conceptual difficulties, magnetism is ideal for inquiry-based learning, in which prediction, experimentation, and explanation can be coordinated. Early scientific learning studies show that children can advance beyond phenomenological descriptions to relational and mechanical explanations when they are involved in continuous, guided exploration of magnetic phenomena. Progress depends on instructional design and how well children's original concepts are solicited, questioned, and reconstructed.

STEM integration in primary and early childhood education has grown internationally in the recent decade alongside interest in early conceptual development. STEM education emphasizes problem solving, design, interdisciplinarity, and the practical application of scientific concepts [1, 2]. STEM techniques have been encouraged in early scientific education to move away from transmissive models and toward learning environments where children actively develop, test, and revise concepts via intentional action. Magnets can be used in simple engineering systems, sorting devices, vehicles, and whimsical structures, making them ideal for such methods. STEM-based magnetism activities with coherent learning goals can assist causal reasoning, iterative testing, and evidence-explanation coordination [3]. Recent Greek and worldwide research supports this. These results indicate a strong epistemic connection between magnetic phenomena and STEM instruction.

Educational robotics have expanded early science learning by providing embodied, interactive systems to examine abstract physical topics. Robotics helps kids externalize their ideas, link actions to consequences, and use scientific methods like prediction, testing, and modification. Robotics is powerful in magnetism because it can apply unseen forces to moving systems, allowing students to examine how magnet position, orientation, and distance effect behavior. Research shows that robotics-supported activities improve engagement, motivation, and conceptual clarity in preschool and primary education, especially when students are encouraged to explain and redesign systems based on observed outcomes. Robotics provide public, shareable artifacts that facilitate debate, meaning negotiation, and communal sense-making, which are crucial to conceptual development in early science learning.

Recent advances in artificial intelligence offer adaptive, dialogic, and representational support for early childhood and primary education. Though new, AI-supported applications can scaffold reasoning, customize feedback, and encourage conceptual engagement by pushing learners to forecast, justify, and reflect on their ideas [4]. AI can visualize invisible processes, simulate interactions, and guide learners through structured inquiry sequences in magnetism learning. Recent studies underline that AI's educational usefulness is not automation but augmentation: it expands instructors' and students' mediational tools, enhancing epistemic dialogue rather than replacing it. AI can assist young learners connect observations to mechanisms and overcome misconceptions when strategically integrated into inquiry-based practices.

STEM integration, instructional robots, and AI are part of a larger pedagogical revolution in early scientific education. These approaches form a dynamic pedagogical environment in which children can study scientific phenomena through numerous representations and modalities [5]. Despite increased empirical study, the literature is scattered. Studies frequently explore individual tools or approaches, short-term interventions, or affective outcomes like engagement and motivation over conceptual learning. There are few integrative, theory-informed syntheses that study how STEM pedagogy, robotics, and AI might be coherently integrated to help challenging physics topics like magnetism in early childhood and primary education.

This paper fills this gap by reviewing current research on teaching magnetism through STEM integration, instructional robotics, and artificial intelligence in early childhood and primary education. The review synthesizes theoretical viewpoints, empirical data, and pedagogical implications with an emphasis on conceptual learning from contemporary Greek educational studies and worldwide literature. Instead of focusing on technology, the analysis investigates magnetism's epistemic structure and how different pedagogical tools and frameworks might help children build, revise, and stabilize their understanding of magnetic phenomena. The essay combines constructivism, conceptual change, sociocultural, and constructionist perspectives to provide an inquiry-driven, conceptually grounded, and developmentally appropriate magnetism teaching paradigm. It contributes to physics and early science education debates regarding how integrated, technology-enhanced pedagogies might meaningfully teach complicated scientific ideas in the early years.

Conceptual and Theoretical Foundations of Magnetism Learning

Magnetism is unique in early physics education since its properties are not visible. Instead of being sensed, magnetic interactions must be inferred from their effects. This epistemic trait exerts enormous cognitive demands on learners, especially in early infancy and primary education, where reasoning is based on visual sensitivity and everyday experience. Research shows that children approach magnetism with robust intuitive theories shaped by surface features like material appearance, size, and weight, leading to persistent misconceptions like the belief that all metals are magnetic, that larger magnets are stronger, or that magnetism can be "used up" through repeated contact. Recent research on kindergarten and primary students' magnetic misconceptions further demonstrates that such ideas are systematic and must be explicitly addressed through carefully planned educational activities [6]. These alternative conceptions are coherent explanatory frameworks that make sense in children's experiential environments. Research in physics education emphasizes that learners' alternative ideas should be treated as epistemically productive resources rather than simple errors, serving as valuable starting points for instructional design [7]. Thus, constructivist learning magnetism entails reorganizing explanatory resources rather than adding new material.

Why magnetism is difficult in the early years is explained by constructivist learning theories. Students bring preconceived notions of forces, materials, and causality that impact their interpretations of new encounters. Children commonly fit magnetism discoveries into existing gravity, physical contact, or electrical schemas, creating hybrid explanations that resist modification. Magnetic attraction might be understood as "stickiness" or as a feature of shiny or weighty things. Empirical investigations in early scientific education suggest that such interpretations can remain consistent despite repeated exposure to magnetic events without specific instructional support [8]. This emphasizes the necessity of building learning environments that actively engage children's existing concepts and inspire reflective restructuring.

Conceptual change provides a more specific paradigm for analyzing learning in areas with profound misunderstandings. This view sees conceptual change as a complex negotiation between competing explanatory models. Learners may have conflicting concepts and use different explanations depending on situation. In magnetism learning, children may accurately identify that magnets attract particular things while believing that magnetism is a property of all metals in another situation. Kindergarten and primary research shows that such misconceptions are resilient and require instructional designs that systematically elicit, challenge, and reconstruct learners' ideas through cycles of prediction, testing, and explanation. Learners transform concepts when they meet anomalous evidence that cannot be effectively integrated into existing schemas and are helped to create more logical and explanatory alternatives.

By making students active investigators rather than passive receivers of information, inquiry-based learning implements these theoretical commitments. Children are encouraged to ask questions, make predictions, develop tests, and assess evidence in inquiry-based classrooms [9]. Inquiry helps students understand magnetism's "mysterious" impact by revealing testable links including attraction and repulsion, distance and orientation dependence, and material selectivity. Early science education studies show that structured inquiry sequences on magnetic phenomena help youngsters advance beyond descriptive accounts to relational and causal explanations. Inquiry alone is insufficient. Investigations without conceptual aims and rigorous structure risk becoming interesting experiences that confirm rather than question prior notions.

Sociocultural theories of learning explain how mediation, language, and social interaction shape scientific understanding. This view holds that learning is shaped by culturally organized activity systems rather than individual cognition. Signs, tools, and social activities connect learners to phenomena they study. This mediation is important in magnetism learning because the phenomena are not observable. Children interpret what they see using representations, gestures, language, and artifacts. Explanatory conversation, cooperative problem solving, and teacher-guided inquiry help students connect observations to conceptual models, according to classroom discourse research. A sociocultural teacher orchestrates activity, frames inquiries, and supports meaning co-construction, not accurate explanations.

This analysis is enhanced by constructionist viewpoints on the epistemic significance of creating and building artifacts. Constructivism says learning is improved when students build public objects that can be examined, discussed, and improved. The externalization of thinking and the development of mechanistic reasoning can be supported in the context of magnetism by building simple systems that use magnets as functional components, such as sorting devices, moving vehicles, or playful mechanisms. Design-based magnet activities in primary education are more likely to help youngsters explain causality and change their minds after seeing results. Empirical evidence from STEM-based teaching interventions in kindergarten further confirms that structured design and inquiry can support young children's conceptual reconstruction of magnetism [10]. These results show that artefact building can transform concepts by making abstract linkages real and discussable.

These theoretical traditions agree that magnetism learning involves carefully planned experiences that coordinate action, representation, and reflection. Learners cannot use perceptual clues alone since magnetic forces are invisible and non-contact. They need help forming inferential linkages between cause and effect, differentiating surface features from mechanisms, and coordinating various representations. For early childhood and primary education, this has significant consequences for instructional design. Activities must be sequenced to elicit initial concepts, allow prediction and testing, and facilitate reflective reconciliation between expectations and findings. To avoid misperceptions, physical, visual, and digital representational tools must match conceptual aims.

The Greek research corpus assessed by Samara and Kotsis and Gavrilas and colleagues supports these claims. When magnetism is taught through conceptually oriented, inquiry-driven sequences in kindergarten and primary classrooms, children can understand material selectivity, attraction and repulsion, and the relational nature of magnetic interactions [11, 12]. These surveys and qualitative studies show that magnetism education without structured methodologies often remains at the level of demonstration and factual explanation, with little impact on students' fundamental notions. These findings emphasize the need to base instructional innovation on a solid learning theory.

Constructivism, conceptual change, sociocultural, and constructionist perspectives agree that magnetism is a paradigmatic notion that demands epistemically rich, mediated, and reflective learning contexts. The theoretical foundations reviewed here support early magnetism education that emphasizes inquiry, design, and technology mediation. They evaluate such approaches based on how well they elicit learners' ideas, provoke cognitive conflict, facilitate explanatory conversation, and permit mental model development and updating. This theoretical synthesis prepares to examine STEM integration, educational robotics, and artificial intelligence as pedagogical frameworks and tools to address magnetism's epistemic challenges in early childhood and primary education.

Mediational Approaches for Magnetism Teaching

1. STEM Integration as a Framework for Magnetism Teaching

STEM education in early childhood and primary science teaching shifts from transmissive models to inquiry, problem solving, design, and functional application of scientific principles. STEM-oriented education integrates science into meaningful activity systems where concepts are used to attain goals, solve issues, and build artifacts. This epistemic position fits well with magnetism, where abstract, invisible forces must be deduced from their effects. STEM integration embeds magnetic phenomena in purposeful tasks and engineering design challenges so children may iteratively explore causal links, test hypotheses, and update explanations [1, 2].

STEM integration fits modern epistemological perspectives of science as practice-oriented and model-based. Because infants cannot directly witness magnetic fields or forces, they must infer fundamental links from interaction patterns in magnetism learning. Magnets "do work" in STEM activities like sorting objects, moving vehicles, and activating systems, highlighting their useful features and encouraging students to think about cause and effect. In primary and early childhood settings, magnets in design-based tasks make children more aware of relational properties like distance, orientation, and material selectivity than surface features. STEM integrates science teaching with technology and engineering, reshaping the classroom epistemic space to use scientific ideas for action and explanation.

Greek educational studies demonstrate STEM-based magnetism instruction's pedagogical benefits. Samara and Kotsis review a growing body of evidence suggesting that integrated STEM activities improve magnetism learning engagement, inquiry, and conceptual clarity [3]. Design-based intervention studies show that young learners learn more about attraction and repulsion, magnetic material selectivity, and magnetic effects' spatial dependence when they participate in STEM-integrated magnetism sequences. These findings support international research demonstrating STEM-integrated inquiry can deepen conceptual learning by integrating abstract concepts to concrete problem-solving contexts [8].

STEM integration relies on engineering design to organize learning. Design jobs include planning, creating, testing, and revising, like scientific study. Such cycles give students frequent chances to forecast, observe, and explain differences in magnetism teaching. When designing a simple magnetic sorting device, children must evaluate which materials will be attracted, how magnet placement impacts performance, and how to optimize the system for a certain goal. Design limitations force learners to express assumptions, test ideas, and update explanations, which is essential to conceptual transformation [11, 13]. Iterative design-based STEM exercises help magnetic interaction mental models become more cohesive.

STEM integration also improves interdisciplinary coherence by integrating science, math, tech, and engineering. This coherence can be used to enable numerous representations and reasoning in magnetism learning. Measurement activities can show how distance affects magnetic attraction, while simple programming or control tasks can show how magnetic interactions affect system behavior. In early childhood and primary education, where students have varied interests and talents, interdisciplinary connections strengthen the learning environment and provide multiple entrance points for understanding [2, 3]. STEM integration helps students develop flexible and transferable knowledge by combining disciplinary lenses.

Additionally, the evidence warns against uncritical STEM adoption as a panacea. STEM activities might become fragmented or shallow without conceptual goals, assessment, and pedagogical sequencing. Several studies warn against reducing STEM to loosely connected "hands-on" tasks that prioritize participation over knowledge [13]. This issue is especially important in magnetism training since youngsters may enjoy manipulating magnets without knowing their mechanisms. To ensure cumulative learning rather than episodic experience in STEM-based magnetism training, the examined studies emphasize explicit conceptual focus, formative evaluation, and reflective discussion.

Teacher mediation of STEM activities and conceptual learning is crucial. Teachers frame questions, guide inquiries, lead discussion, and assist students with relating observations to explanations. Research on pre-service primary teachers further indicates that efficacy beliefs in physics teaching are a critical factor shaping instructional confidence, pedagogical decisions, and willingness to engage with demanding physics concepts [14]. Other researches show that teachers with STEM pedagogy training are more likely to construct conceptually grounded and developmentally appropriate activities [15, 12]. STEM integration's instructional rationale and ability to address magnetism learning's epistemic difficulties are examined here. Mandrikas and Stefanidou similarly highlight that teachers' views play a decisive role in how STEM education is interpreted and enacted in primary classrooms [16].

STEM integration is theoretically consistent with constructivism, conceptual transformation, and sociocultural pedagogy. STEM-based magnetism training empowers learners to restructure naïve notions through intentional engagement, collaborative problem-solving, and functional use of scientific principles. It provides a natural environment for mediational tools like instructional robotics and digital technology, which expand representational and interactive possibilities. STEM integration provides a pedagogical framework for various tools and methodologies.

The findings suggests that STEM integration improves magnetism instruction in early childhood and primary education. Investigation, design, and multidisciplinary coherence fit magnetic phenomena' conceptual needs. These benefits need careful instructional design, conceptual growth, and skillful mediation. STEM is a systematic approach to learning that demands deliberate alignment of goals, activities, and representations, not just an organizational structure. This notion is essential for studying educational robotics' complementing role in magnetism learning, which is the following section.

2. Educational Robotics as a Mediational Tool in Magnetism Learning

Educational robotics is a strong pedagogical resource in early childhood and primary education because it mediates learning through bodily interaction, iterative experimentation, and collaborative problem solving. Science education uses robots to explore, test, and discuss abstract physical topics with young learners. In magnetism, students must infer invisible forces and relationship qualities from observable outcomes, making mediation important. Robotics lets kids externalize their thinking, coordinate actions with outcomes, and mimic scientific cycles of prediction, testing, and revision by embedding magnetic interactions in moving, responsive systems.

Robotics' instructional value can be understood through sociocultural mediation and constructionism. Tools and artifacts shape how people interact with phenomena and each other, according to sociocultural theories. Robotics structures action focuses attention on specific relations, and provides a shared reference point for discourse and explanation. In magnetism activities, children negotiate meaning, establish hypotheses, and test explanations around magnetic robots. The shared artefacts encourage explanatory discussion and collaborative sense-making, which are crucial to conceptual development in early science learning, according to classroom interaction research.

Constructionist views emphasize the epistemic value of building and refining artifacts. Constructionism says learning improves when students design, build, and exchange meaningful objects. As children develop or change systems in which magnets guide movement, initiate operations, or sort objects, robotics-supported magnetism activities follow this premise. Students learn mechanical reasoning by considering how magnetic interactions affect system behavior in these design assignments. In primary education, design-based robotics exercises encourage students to construct causal explanations and revise their ideas in response to unanticipated outcomes. Iterative design and debugging methods allow learners to repeatedly encounter differences between purpose and outcome, which drives conceptual transformation.

Embodied interaction is another important robotics pedagogical affordance. Cognition, action, and perception are interwoven in early childhood and elementary education. Robotics exercises that incorporate physical manipulation, movement, and spatial reasoning help kids interact with abstract concepts. This embodied dimension is powerful in magnetism learning because children can immediately experience how magnet position, orientation, and distance affect movement and interaction. Such experiences link spatial arrangements to dynamic consequences, fostering relational reasoning. Embodied engagement improves attention, persistence, and willingness to revise initial ideas, fostering creative struggle and conceptual growth in early scientific education robotics studies [17, 18].

Greek educational research demonstrates how educational robots has been integrated into STEM and early scientific study. Samara and Kotsis describe how robotics has been integrated into elementary education through project-based learning, problem-solving, and multidisciplinary STEM projects [19]. A complementary bibliographic review highlights the dominant methodological approaches adopted in Greek primary education and documents teachers' attitudes toward educational robotics [20]. In magnetism-related activities, robots embed invisible forces in systems that move, halt, or change direction upon magnetic interactions. Teachers and academics say such exercises allow children to hypothesize systems, manipulate concepts, and have explanatory conversations. Gavrilas and colleagues found that preschool and primary teachers value educational robots for improving engagement and experience learning, especially in abstract areas [12].

Intervention studies on magnetism in kindergarten and primary classrooms demonstrate the conceptual advantages of robotics-supported inquiry. Earlier STEM-based instructional interventions in kindergarten already showed that structured design and inquiry activities can support young children's causal and relational understanding of magnetism [10]. Samara and Kotsis found that robotics-enhanced STEM activities improved children's understanding of material selectivity, attraction and repulsion, and magnetic effects' spatial configuration dependence [11]. These benefits were linked to higher involvement, better explanatory language, and more cohesive mental models. International research shows that robotics can help phenomenological descriptions become mechanistic explanations by making causal linkages apparent and discussable [21].

Robotics are not always transformative, according to the literature. Robotics activities can end rather than methods of learning without appropriate pedagogical design. Several research shows that robotics integration involves explicit learning goals, systematic coaching, and reflection and debate [19, 22]. In magnetism, this includes linking tasks to scientific concepts and encouraging students to express and deepen their understanding rather than just handle gadgets. In early childhood settings, where novelty can easily dominate, the potential of "technological distraction," when attention is focused on the tool rather than the underlying phenomenon, is well-documented in education technology research.

Developmental appropriateness is also important. Robotics offers many chances for inquiry, but activities must be customized to young learners' cognitive, verbal, and motor capacities. Simple platforms like Bee-Bot or other age-appropriate robots can be utilized in preschools to construct repeating inquiry cycles using narratives, play-based structures, and clear limits [23]. Such designs allow youngsters to explore magnetic phenomena in meaningful and reasonable ways, fostering explanatory thinking without overwhelming them.

The instructor is crucial to robotics-supported magnetism learning. Teachers structure activities, ask questions, lead observations, and encourage explanations. Empirical research assessing teacher readiness for educational robotics integration in preschool and primary education further confirms that pedagogical competence and preparedness are decisive factors for effective implementation [24]. Although a companion research analyzes teacher views and preparation, robotics does not eliminate the requirement for excellent pedagogy; it amplifies it. The most successful implementations in the literature involve teachers knowing what children should learn about magnetism and how robotics activities promote that learning. This supports the idea that educational robotics should supplement well-designed instructional tactics rather than replace them.

By fostering dialogue, experimentation, and shared sense-making, education robotics reshapes the epistemic space of the classroom. Robotics helps pupils graduate from static examples to dynamic systems with visible magnetic interactions in magnetism training. This change promotes mechanical reasoning because students must explain what and why things happen. It also supports design-based STEM integration, establishing robots as a supplementary resource in instructional architecture.

The evidence suggests that educational robots improves magnetism instruction in early childhood and primary education. Its ability to externalize thinking, facilitate iterative inquiry, and promote collaboration matches modern learning theories and physical science epistemic standards. However, it requires careful pedagogy, developmental sensitivity, and expert mediation. Thus, robotics should be seen as a potent mediational instrument that, when integrated into inquiry-driven STEM frameworks, may deepen conceptual engagement with magnetic phenomena. This perspective leads naturally to the next part on artificial intelligence as a complementary mediation in magnetism learning.

3. Artificial Intelligence as a Conceptual and Dialogic Scaffold in Magnetism Learning

Artificial intelligence in early childhood and primary scientific education is a recent but quickly growing trend that has major implications for teaching conceptually challenging subjects like magnetism. Artificial intelligence uses adaptive, dialogic, and representational processes to personalize learning trajectories, scaffold reasoning, and provide immediate feedback, unlike educational robotics, which uses embodied interaction and physical manipulation. AI-supported environments can enable conceptual development and inquiry-based learning in magnetism, where students must deduce invisible forces and causal mechanisms from observable outcomes.

Theories suggest that artificial intelligence expands learners' mediational options. Tools influence activity system action and thought in sociocultural contexts. As cognitive and dialogic mediators, AI systems that push learners to forecast outcomes, ask follow-up questions, or illustrate dynamic processes structure attention and guide interpretation. This mediation is useful in magnetism learning because children cannot directly observe magnetic fields or forces. AI-supported visualizations and simulations can highlight relationship properties by coherently linking cause and effect, promoting the formation of more complex mental models [4, 25].

Recent Greek preschool education research shows that AI solutions can improve magnetism classroom engagement and conceptual knowledge. According to Samara and Kotsis, AI-supported activities helped young learners explore magnetic phenomena through interactive prompts, dynamic representations, and guided questioning, helping them articulate and develop their thoughts [4]. Children were invited to predict which things magnets would attract, justify their choices, and consider inconsistencies between expectations and observations. These procedures are similar to science epistemic practices and conceptual change theory, which emphasizes explicit and evaluative learning.

AI's educational affordances include adaptive feedback. AI systems can provide real-time suggestions, reminders, and customized representations to learners, unlike static teaching resources. Adaptive feedback can help magnetism learners overcome misunderstandings like that all metals are magnetic or that magnetism declines with use by suggesting counterexamples and encouraging reconsideration. When used properly, intelligent tutoring systems and conversational agents can improve conceptual understanding in science education [5]. These findings suggest that AI could serve as a cognitive apprenticeship, showing beginners expert-like reasoning processes.

AI's pedagogical role includes dialogic support. Question-and-answer sessions using AI-powered conversational agents can promote explanation, justification, and reflection. Dialogic engagement can be especially powerful in early childhood and elementary education, where language and conceptual development are strongly linked. AI systems can maintain epistemic conversation and encourage learners to use explanatory reasoning by asking follow-up questions, clarifying, or pointing out contradictions. AI-supported inquiry research shows that dialogic scaffolding incorporated in meaningful action and accompanied by teacher mediation can deepen scientific interest [5].

Visualization and dynamic representation are further AI affordances. Magnetic fields and forces are not directly observable; therefore students struggle to link effects to mechanisms. By showing patterns and relationships in interactions, AI-supported visualizations can help close this gap. Simulations can highlight how field lines express relational structure or how attraction intensity varies with distance or direction. When used with physical experimentation, such representations can help coordinate different sources of knowledge and improve conceptual comprehension. However, badly created visualizations might perpetuate misconceptions rather than correct them, emphasizing the need for careful pedagogical framing and interpretation [25].

Artificial intelligence has instructional potential, but it requires intelligent design, ethical awareness, and strong teacher mediation. Teachers must present AI as a tool rather than a truth-giver since young students may struggle to distinguish between human and machine authority. Due to vulnerable learners and inadequate institutional safeguards, early childhood environments raise ethical questions about data privacy, algorithm transparency, and access equality [5]. According to Greek research, instructors understand AI's potential to scaffold learning and encourage differentiation, but they worry about their own readiness to apply it responsibly [4]. A companion research analyzes teacher perspectives, but these findings emphasize the need to place AI in a pedagogical and ethical context.

Additionally, AI does not replace human contact or hands-on investigation. Physical manipulation of magnets, effect observation, and collaborative discussion are still key components of magnetism education. AI augments representational and dialogic tools for teachers and students. AI can support prediction, explanation, and reflection in inquiry-based routines, complementing educational robots' embodied engagement and STEM pedagogy's problem-solving focus. This integrated perspective aligns with sociocultural ideas of learning as mediated action and constructionist emphasis on meaningful engagement.

STEM integration, instructional robots, and AI offer a rich pedagogical environment with numerous mediations. This convergence is promising for magnetism since it meets both its epistemological issues and young learners' developmental demands. AI provides adaptive, dialogic, and representational assistance to help learners connect observations to mechanisms and overcome misconceptions. It works best when aligned with instructional aims and mediated by qualified teachers.

The evidence suggests that individualized scaffolding, dialogic support, and dynamic visualization can improve magnetism instruction in early childhood and primary education with artificial intelligence. However, the evidence is clear that AI's educational effectiveness depends on intelligent pedagogical design, ethical awareness, and inquiry-driven learning environments. Thus, AI should be seen as a complementary mediational instrument that, when combined with STEM pedagogy and instructional robots, can deepen conceptual engagement with magnetic phenomena. This perspective provides the stage for synthesizing various techniques into an integrated magnetism instruction pedagogical model in the next section.

Toward an Integrated Pedagogical Model for Magnetism

STEM integration, instructional robots, and artificial intelligence are diverse but complimentary magnetism learning methods for early childhood and primary education. While each technique has unique affordances, they work best when integrated into a single instructional design. An integrated pedagogical model integrates technologies and methodologies around epistemic aims, conceptual progressions, and learning processes. Because magnetism is invisible, non-contact, and relational, several mediations are needed to assist sense-making [5].

Epistemic alignment between magnetism and STEM, robotics, and AI educational logics underpins an integrated paradigm. Interactions define magnetism, not surface features. STEM pedagogy emphasizes function, design, and problem solving, using magnetic interactions to achieve system goals. Educational robotics makes these connections operational and visible in dynamic environments. AI provides adaptive, dialogic, and representational frameworks for interpretation and reflection. These elements provide a learning environment where children can act on events, notice consequences, communicate ideas, and change explanations through sustained inquiry [21].

Coordinating action, representation, and reflection is key to the integrated model. Children's early magnetism learning begins with action: handling magnets, building systems, and watching results. Magnetic interactions are included in significant STEM assignments in robotics-enhanced STEM activities. After these experiences, AI-supported technologies ask learners to forecast outcomes, illustrate relations, and explain. Guided discussion, questioning, and comparing expectations to observations aid reflection. This triadic coordination integrates experiential engagement with cognitive restructuring, which is essential for conceptual transformation [4].

Iterative design as epistemic practice is another integrated model component. STEM pedagogy relies on design-based planning, testing, and redesigning, which robotics settings support. In magnetism learning, cycles let kids see how spatial layout, orientation, and material choice effect system behavior. AI can improve these processes by providing rapid feedback, offering alternatives, or identifying patterns. Iteration encourages creative struggle and allows learners to challenge initial notions, which is crucial for conceptual development in domains with persistent misconceptions [11].

The integrated model relies on representation, especially when magnetic forces are invisible. Robots and built devices provide concrete examples. Diagrams and AI-supported simulations clarify relational patterns. Language, gestures, and story framing help communicate meaning. Sociocultural theories highlight that representational tools impact how learners perceive and interpret phenomena [26, 19]. These representational resources are carefully orchestrated via an integrated instructional paradigm to refine mental models.

The order of learning experiences matters too. Effective magnetism training starts with learners' thoughts and experiences, not definitions. Exploratory exercises can reveal intuitive assumptions and misconceptions, enabling targeted intervention. Design problems and robotics-supported tasks can cause cognitive conflict by producing outcomes that are difficult to explain with simple ideas. AI-supported prompts and visualizations help learners reconcile these disparities and construct more logical explanations. This path from elicitation to challenge to reconstruction is compatible with conceptual change theory and validated by early scientific education empirical investigations [25].

Dialog and collaboration are key to the integrated concept. Learning magnetism is a social process in which ideas are proposed, questioned, and developed. Students collaborate on robotics and STEM projects because they must coordinate actions and negotiate design decisions. AI can encourage group discussion, questioning, and introspection. Teacher mediation controls these interactions, frames activities, and draws attention to key elements. Explanatory discussion and cooperative problem solving enhance conceptual development in early science learning, according to research.

Further guidelines include developmental appropriateness. Young learners' cognitive, linguistic, and socio-emotional needs must be considered in an integrated paradigm. Play-based structures, storytelling, and familiar surroundings can make magnetism activities meaningful and accessible. Choose and create robotics platforms and AI applications with simplicity, transparency, and usability in mind. Technology that is developmentally sensitive and pedagogically framed allows preschool and primary students to work productively with complicated topics without being overwhelmed [17, 23].

The integrated pedagogical concept emphasizes teachers as designers, mediators, and interpreters. Technologies empower action and expression, but they do not dictate learning results. Teachers scaffold inquiry, match activities with conceptual goals, and facilitate reflection. In a companion paper, teacher perceptions and readiness are examined, but any integrated approach relies on teachers' pedagogical content knowledge and ability to manage complex learning environments.

Analytically, STEM, robotics, and AI integration creates a pedagogical environment with numerous mediations. STEM gives problem-solving settings and interdisciplinary coherence, robotics gives embodied and dynamic interaction, and AI gives adaptive and dialogic scaffolding. Their integration enables extensive epistemic engagement with magnetic phenomena, helping the move from intuitive, phenomenological reasoning to relational and mechanical comprehension. This ecosystemic paradigm prioritizes coherence, alignment, and purpose over additive technology integration models.

The Greek research corpus shows how integration can be done. Design-based studies in kindergarten and primary classrooms show that STEM activities with robotics and digital tools increase engagement, explanatory discourse, and conceptual gains [11, 4]. These findings confirm international research demonstrating integrated, inquiry-driven techniques that facilitate deep learning better than standalone treatments [8, 21].

The literature emphasizes coherence and intentionality. Fragmented or shallow integration might restrict conceptual concentration and learning to episodes. Thus, integrated pedagogy requires clear learning pathways, conceptual goals, and formative assessment. AI can provide real-time feedback and student replies for evaluation, but humans must evaluate and make pedagogical decisions [5].

Epistemic alignment, iterative design, representational richness, dialogic engagement, developmental sensitivity, and competent mediation define an integrated pedagogical approach for magnetism in early childhood and primary education. A methodology that coordinates STEM pedagogy, instructional robotics, and artificial intelligence around similar conceptual goals solves magnetic phenomena' unique obstacles and uses each approach's strengths. This integration does not simplify magnetism learning; it prepares young learners to handle complexity. The paradigm proposes reimagining early magnetism teaching as a location of serious inquiry, design, and meaning-making, laying the groundwork for discussing bigger implications and future perspectives.

Discussion

This synthesis uses magnetism as a privileged conceptual domain to examine the pedagogical potential of integrated STEM education, educational robots, and artificial intelligence in early childhood and primary education. The analysis showed that magnetism's epistemic characteristics---invisibility, action at a distance, and relational structure---create learning needs that demonstration-based techniques cannot meet. These demands require inquiry, mediation, representation, and iterative sense-making pedagogies. This integrated instructional model addresses this difficulty by connecting STEM's functional logic, robotics' embodied affordances, and AI's adaptive, dialogic skills around shared conceptual aims.

Epistemic alignment as a design principle is a key contribution of this review. Instead of seeing STEM, robotics, and AI as interchangeable break throughs, the study showed that each has particular affordances that correspond to magnetism learning. STEM pedagogy emphasizes problem solving, design, and functional application, making magnetic interactions instruments rather than abstract facts [1, 2]. Educational robotics uses embodied and dynamic systems to observe invisible forces [19, 12]. AI provides adaptive scaffolding, dialogic support, and representational richness for interpretation and reflection [4]. These parts work synergistically to create a learning environment that coordinates action, representation, and explanation.

In physics education research, this integration tackles longstanding magnetism teaching problems. Over several decades, research has shown that misconceptions remain and conceptual change is difficult in this domain [25]. A mismatch between magnetism's epistemic structure and its instructional forms may be the cause of these issues, according to this synthesis. When magnetism is taught mostly through verbal explanation or isolated demonstrations, students must reconcile unseen forces with perceptual experience without mediation. Integrated pedagogies allow students to study phenomena through action, dialogue, and representation. This multiplicity is crucial in early infancy and elementary education, when cognitive and linguistic resources are still growing.

Another major contribution of the integrated paradigm is iterative design and inquiry. STEM pedagogy and robotics-supported learning emphasize design-based planning, testing, and rethinking. According to conceptual change theory, continuous exposure to disparities between expectations and outcomes is essential for learners to redesign naïve beliefs [13]. AI can reinforce contemplation and metacognition by providing quick feedback, suggesting alternate tactics, or highlighting data patterns. These processes promote prolonged epistemic engagement, in which learners focus on explanation and understanding over time rather than perceiving activities as isolated events.

The review emphasizes representation's importance in magnetism learning. Since magnetic forces and fields are not visible, learners must use representational skills to understand them. Robots and built devices provide concrete examples. AI-supported visualizations and simulations clarify relational structures. Language and gestures convey and negotiate meaning. Tools and signs influence how people see and interpret phenomena, according to sociocultural theories [26]. Since no single representation is sufficient, the integrated model carefully orchestrates these representational resources. Instead, conceptual knowledge comes from coordinating representations across contexts.

Developmental sensitivity is another benefit of this synthesis. Much STEM, robotics, and AI research has focused on secondary or tertiary education students. This article emphasizes play, narrative, and physical engagement in conceptual formation by focusing on early life and elementary education. The evaluated studies show that developmentally attuned and pedagogically framed exercises can help young learners understand complicated concepts like magnetism [17, 23]. This contradicts deficit-oriented ideas that underestimate young children's capacities and promotes conceptual work in early science education.

The approach also emphasizes the teacher's crucial function as mediator and learning environment designer. Technologies generate possibilities that must be pedagogically realized, not learning outcomes. Teachers that set conceptual goals, coordinate inquiry, and encourage reflective conversation have the most successful implementations [19, 12]. A companion paper examines teacher views and preparation, but this discussion underscores the idea that pedagogical content knowledge and instructional design skills are crucial to integrated approaches. Teacher education and professional development must cover technical, epistemic, and pedagogical skills.

This discussion relies on contextually grounded information from the Greek research corpus on integrated pedagogies. Samara, Kotsis, Gavrilas, and colleagues studied kindergarten play-based robotics and primary STEM-integrated inquiry sequences. These studies show that integration within existing curricular frameworks can improve conceptual knowledge and engagement [11, 12]. They also show implementation quality heterogeneity, emphasizing the need for coherence, planning, and assistance.

This synthesis also finds literature gaps and limitations. Many studies are short-term, making conceptual gains hard to measure. How early encounters with integrated pedagogies affect later knowledge of physics ideas requires longitudinal investigation. The evidence is mostly qualitative or from small samples, limiting generalizability. More detailed evaluations of how design aspects like activity sequencing and AI prompts affect learning are needed. Design-based, mixed-methods, and longitudinal research will be needed to fill these gaps.

Technology integration's ethical and equity issues are another barrier. AI creates data privacy, algorithmic transparency, and access concerns. This paper does not address these difficulties, but they are crucial to responsible implementation and deserve further study [5]. Similarly, resource and infrastructural gaps might affect integrated approach practicality, worsening inequities. Integrated pedagogies should be seen as instructional innovations and as parts of educational systems.

Despite these limitations, the integrated educational paradigm presented here provides a consistent foundation for reconsidering early magnetism teaching. It emphasizes alignment, mediation, and purpose above fragmentation and technological determinism. The paradigm supports physics education arguments about how to meaningfully convey complicated scientific concepts to young students by locating STEM, robotics, and AI within a shared epistemic stance. It fits science education trends that stress inquiry, design, and social knowledge building.

The paper uses magnetism as a case study but does not imply the paradigm is unique. Due to its conceptual difficulties and applicability for functional, design-based inquiry, magnetism offers as an analytically powerful example. Other hard areas in early physics education, such as electricity, sound, and light, may benefit from epistemic alignment, iterative inquiry, representational richness, dialogic mediation, and developmental sensitivity. Future research could examine the model's relevance to various domains, expanding its reach.

This discussion has placed the integrated pedagogical paradigm in the context of physics education research and early scientific education. Using STEM, instructional robotics, and artificial intelligence to coordinate action, representation, and reflection in early magnetism learning has been suggested. Young learners can actively engage with complexity through the model, which does not simplify magnetism concepts. It helps define early physics education as cognitively substantive, developmentally suitable, and pedagogically innovative.

Implications for Early Physics Education

This article's integrated pedagogical paradigm affects early physics education design, implementation, and theory. The model challenges assumptions about what is feasible and appropriate in early childhood and primary science classrooms by positioning magnetism as a conceptually demanding domain that benefits from STEM pedagogy, educational robotics, and artificial intelligence. It empowers young learners to engage in inquiry, design, and meaning-making rather than passively receiving simplified knowledge. Curriculum design, instructional practice, and early physics education epistemology are affected by this transition.

The approach argues that magnetism should be taught as a relational system of interactions that may be investigated through intentional activity rather than as a standalone topic or a collection of factual assertions at the curricular level. By incorporating magnetism into STEM tasks like engineering, problem-solving, and design, curriculum frameworks can promote this attitude. Children can experience magnetic phenomena as functioning components of systems rather than abstract features of objects. Curriculum that emphasizes functional application and inquiry helps students acquire relational and mechanistic understanding [11,8]. This means shifting from linear, content-heavy sequencing to exploration, iteration, and conceptual refinement.

The integrated paradigm also impacts instructional design. Teachers should create learning sequences that coordinate action, representation, and reflection to provide various entry points for understanding. This involves hands-on exploration, robotics-supported activities, AI-mediated communication, and structured discussion. A learning sequence might start with free magnet exploration, then move on to a robotic system design task with AI prompts for prediction and explanation. Sequences that elicit learners' ideas, generate cognitive conflict, and encourage meaning co-construction follow constructivist and sociocultural principles. The literature discussed in this article shows that such designs can help early learners interact conceptually [17].

Assessment in early physics education is affected by the integrated model as well. Traditional evaluation methods, which focus on factual memory, are unsuitable for inquiry- and design-based learning. Instead, formative assessments should focus on learners' reasoning, explanations, and representations. Artificial intelligence-supported systems can provide real-time feedback, capture learner answers, and identify thinking patterns [5]. Teachers must analyze such tools carefully and comprehend the conceptual aims of instruction. In this view, assessment is part of learning rather than a distinct evaluation.

The consequences go beyond classroom practice to teacher preparation. A companion study analyzes teacher education, but the integrated model needs teachers to have technical skills, pedagogical subject knowledge, and epistemic awareness. Teachers must learn about magnetism, tool affordances and constraints, and inquiry-based learning. So, professional development programs should go beyond technology training to address pedagogical and theoretical rationales for integration. Greek studies demonstrate that holistic preparation helps teachers develop cohesive, theoretically grounded learning experiences [15, 12].

The paradigm also affects how early physics education is viewed in education. It contradicts deficit-oriented narratives that underestimate children's cognitive abilities by showing that young learners can use mediated inquiry to grasp difficult topics. It promotes intellectually substantial, epistemically rich, and developmentally appropriate early physics education. Contemporary calls to rethink early scientific education as a location of genuine knowledge building rather than preparation for "real" science learning [17, 2] support this view.

Equity matters too. Interactive pedagogies that mix hands-on exploration, robotics, and AI can engage diverse learners by giving multiple ways of participation and representation. Children who struggle with language can show comprehension through design and action, while those who need visual assistance can use simulations and representations. But these benefits depend on equitable resource availability and educational methods that value different expressions. Infrastructure and support discrepancies can affect integration feasibility, worsening inequality [5]. Policymakers and educational leaders must help schools and teachers in developing inclusive and sustainable integrated methods.

Finally, the integrated approach challenges early physics education theory-practice relationships. Pedagogical innovation is grounded in learning theory and empirical research, demonstrating a design-based attitude in which theory informs practice and practice refines theory. A field with rapid technological change, where new tools can outstrip educational understanding, requires this perspective. This paradigm provides an epistemically valid and educationally useful framework for evaluating and integrating emerging technologies.

This approach has significance beyond magnetism as a content area. They address how intelligent pedagogy and technology might encourage inquiry, conceptual development, and epistemic involvement in early physics education. The integrated paradigm may transform early physics education into rich, meaningful learning by linking STEM, educational robotics, and AI around shared conceptual goals.

Conclusions

This paper argues that magnetism provides unique epistemic issues in early childhood and primary education because of its invisibility, non-contact interaction, and relationship structure. Traditional methods, such as demonstration and verbal explanation, are unsuitable for these issues and leave students with fractured or shallow comprehension. In response, the paper constructed and defined an integrated pedagogical model that links STEM, educational robotics, and AI around conceptual and epistemic goals.

The data shows that each strategy has unique magnetism learning affordances. STEM integrates magnetic phenomena into problem-solving and design, emphasizing function and causality. Educational robotics uses embodied, dynamic systems to make invisible forces visible and support mechanical reasoning. AI guides interpretation, reflection, and conceptual change with adaptive, dialogic, and representational scaffolds. These approaches form an educational ecosystem that coordinates action, representation, and debate to sustain epistemic engagement when integrated coherently.

Epistemic alignment as a design principle is a key contribution of this work. The integrated model stresses aligning instructional tools with domain conceptual structure rather than adding technologies to current practices. To learn magnetism, activities should emphasize relationship features, provide opportunities for prediction and testing, and aid in reconstructing naïve concepts. Iterative design, representational richness, dialogic interaction, and developmental sensitivity are also stressed in the approach. Constructivist, conceptual transformation, sociocultural, and constructionist learning theories underpin these concepts, reinforced by Greek and worldwide empirical findings.

The text also views early physics education as conceptual labor rather than preparation for later learning. It contradicts deficit-oriented conceptions and supports a more ambitious vision of early scientific education by showing that young learners may constructively interact with complicated topics through mediated inquiry and design-based engagement. As mentioned above, this vision affects curriculum design, instructional practice, assessment, and teacher education.

This synthesis and the literature have limitations, as the article admits. Most empirical evidence comes from short-term interventions and small samples, underscoring the need for longitudinal and large-scale studies. More detailed evaluations of how design aspects affect learning processes and results are needed. Future study should focus on technology integration ethics and equity, especially in artificial intelligence.

Despite these limitations, the integrated educational paradigm presented here provides a cohesive and theoretically informed foundation for redesigning early magnetism training. It outlines concepts and possibilities for design, study, and practice, not answers. By integrating STEM, educational robots, and AI into a unified epistemic perspective, the model adds to physics education discussions about how to teach complicated scientific concepts to young students.

In conclusion, magnetism represents both a content domain and a good analytical case for examining integrated, technology-enhanced pedagogies in early physics education. Epistemic alignment, mediation, and developmental sensitivity can help young learners connect deeply with difficult topics, according to this synthesis. This viewpoint encourages additional research, experimentation, and conversation in the subject and emphasizes the importance of intellectual rigor, creativity, and innovation in early physics education.

References

1. Bybee RW. The case for STEM education: Challenges and opportunities. NSTA Press, 2013.
2. English LD. STEM education K-12: Perspectives on integration. Int J STEM Educ. 2016; 3:3. Doi: 10.1186/s40594-016-0036-1
3. Samara V, Kotsis KT. The use of new technologies and robotics (STEM) in the teaching of sciences in primary education: The concept of magnetism: A bibliographic review. Eur J Educ Stud. 2023; 10(2):51-64. Doi: 10.46827/ejes.v10i2.4652
4. Samara V, Kotsis KT. Use of the artificial intelligence in teaching the concept of magnetism in preschool education. J Digit Educ Technol. 2024; 4(2):ep2419. Doi: 10.30935/jdet/14864
5. Fayzullina AR, Filippova AA, Garnova NY, Astakhov DV, Kalmazova N, Zaripova ZF. Artificial intelligence in science education: A systematic review of applications, impacts, and challenges. Contemp Educ Technol. 2025; 17(4):ep613. Doi: 10.30935/cedtech/17519
6. Samara V, Kotsis KT. Research on kindergarten and primary school students' magnetic misconceptions and how to plan educational activities. EIKI J Eff Teach Methods. 2024; 2(2):10-14. Doi: 10.59652/jetm.v2i2.124
7. Kotsis KT. Alternative ideas about concepts of physics are a timelessly valuable tool for physics education. Eurasian J Sci Environ Educ. 2023; 3(2):83-97. Doi: 10.30935/ejsee/13776
8. Wang G, Chen S. Integrating STEM principles into kindergarten science education: Effects of inquiry-based activities on knowledge acquisition and skills development. Int J Knowl Manag. 2025; 21(1):383964. Doi: 10.4018/IJKM.383964
9. Kotsis KT. The significance of experiments in inquiry-based science teaching. Eur J Educ Pedag. 2024; 5(2):86-92. Doi: 10.24018/ejedu.2024.5.2.815
10. Samara V, Kotsis KT. A teaching intervention for magnetism using STEM in kindergarten. Int J Prof Dev Learn Learn. 2023; 5(2):ep2312. Doi: 10.30935/ijpdll/13667
11. Samara V, Kotsis KT. The use of STEM as a tool for teaching the concept of magnetism in kindergarten. J Res Environ Sci Educ. 2025; 2(1):1-17. Doi: 10.70232/jrese.v2i1.1
12. Gavrilas L, Kotsis KT. Investigating perceptions of primary and preschool educators regarding incorporation of educational robotics into STEM education. Contemp Math Sci Educ. 2024; 5(1):ep24003. Doi: 10.30935/conmaths/14384
13. Martín-Páez T, Aguilera D, Perales-Palacios FJ, Vílchez-González JM. What are we talking about when we talk about STEM education? A review of the literature. Sci Educ. 2019; 103(4):799-822. Doi: 10.1002/sce.21522
14. Stylos G, Kamtsios S, Kotsis KT. Assessment of Greek pre-service primary teachers' efficacy beliefs in physics teaching. J Sci Teach Educ. 2022; 34(1):44-62. Doi: 10.1080/1046560X.2021.2023959
15. Samara V, Kotsis KT. Primary school teachers' perceptions of using STEM in the classroom: Attitudes, obstacles, and suggestions. Contemp Math Sci Educ. 2023; 4(2):ep23018. Doi: 10.30935/conmaths/13298
16. Mandrikas A, Stefanidou C. Greek primary teachers' views about STEM education. Eur J Sci Math Educ. 2025; 13(2):119-136. Doi: 10.30935/scimath/16162

17. Bers MU. Coding as a playground: Programming and computational thinking in the early childhood classroom. 2nd ed. Routledge, 2020. Doi: 10.4324/9781003022602
18. Zviel-Girshin R, Rosenberg N. Enhancing early STEM engagement: The impact of inquiry-based robotics projects on first-grade students' problem-solving self-efficacy and collaborative attitudes. Educ Sci. 2025; 15(10):1404. Doi: 10.3390/educsci15101404
19. Samara V, Kotsis KT. Educational robotics in primary education in Greece: Methodological approaches and attitudes of teachers: A bibliographic review. Eur J Educ Pedag. 2023; 4(2):194-206. Doi: 10.24018/ejedu.2023.4.2.629
20. Samara V, Kotsis KT. Educational robotics in primary education in Greece: Methodological approaches and attitudes of teachers: A bibliographic review. Eur J Educ Pedag. 2023; 4(2):194-206. Doi: 10.24018/ejedu.2023.4.2.629
21. Pacaci C, Ustun U, Ozdemir OF. Effectiveness of conceptual change strategies in science education: A meta-analysis. J Res Sci Teach. 2024; 61(6):1263-1325. Doi: 10.1002/tea.21887
22. Gavrilas L, Kotsis KT, Papanikolaou MS. The challenges encountered by preschool and primary educators in implementing educational robotics. Res Sci Technol Educ. 2025; 1-29. Doi: 10.1080/02635143.2025.2578308
23. Samara V, Kotsis KT. Robotic Christmas activities with Beebot: A STEM application for preschool education. J Sci Educ Res. 2025; 9(1):21-31. Doi: 10.21831/jser.v9i1.77862
24. Gavrilas L, Kotsis KT, Papanikolaou MS. Assessing teacher readiness for educational robotics integration in primary and preschool education. Educ 3-13, 2024. Doi: 10.1080/03004279.2023.2300699
25. Khek S. Investigating students' misconceptions in learning magnetic field and force for Cambodian high schools. J Innov Adv Methodol STEM Educ. 2025; 2(5):361-376. Doi: https://so13.tci-thaijo.org/index.php/j_iamstem/article/view/2426
26. Vygotsky LS. Mind in society: The development of higher psychological processes. Harvard University Press, 1978.