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Teaching Physics Concepts in Primary Education: Evidence from Hands-on Experiments, Inquiry, and Digital Technologies

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Abstract
Research at the primary education level is still scattered and overshadowed by studies undertaken at the secondary and higher education levels, despite the fact that primary education is gradually coming to be recognized as an essential stage for the development of core physics concepts. The purpose of this Mini Review is to assess the impact that three key instructional approaches, hands-on experiments, inquiry-based learning, and digital and robotics-based tools, have on conceptual comprehension in elementary physics. This Mini Review provides a synthesis of recent evidence on these different approaches. The findings indicate that young students come to school having solid intuitive conceptions that have been sculpted by perception and common language, as well as by exposure to narrative forms such as traditional fairy tales that embed non-scientific explanations of natural phenomena. These ideas can be found in a variety of domains, including force, motion, heat, temperature, energy, and light. It is not enough for instruction to just place an emphasis on involvement in order to bring about conceptual change; rather, effective designs make student thinking clear, provide organized inquiry sequences, and enable representational transformations. Comparative evidence demonstrates that simple hands-on apparatus can promote conceptual gains when prediction, explanation, and reflection are embedded, while virtual labs and robotics offer unique affordances for visualization and control of variables, although they require strong pedagogical scaffolding. Within the scope of this study, cross-cutting difficulties pertaining to language, cognitive load, and assessment techniques are brought to light. Additionally, research gaps pertaining to longitudinal development, transfer of understanding, and the incorporation of digital technologies in early-years science are identified. The implications for the design of curricula and the preparation of teachers are examined, with a particular emphasis on the development of early physics education that is conceptually cohesive.

Keywords: Primary Education, Physics Learning, Hands-on Experiments, Inquiry-Based Learning, Digital Technologies, Conceptual Understanding

Introduction

It is becoming more acknowledged that it is vital for kids to develop a strong understanding of fundamental physics ideas during their primary school in order for them to participate in science and technology with a long-term perspective. Although children come to school with a wealth of practical knowledge regarding motion, balance, light, and thermal phenomena, this everyday knowledge is frequently organized in ways that are significantly different from the canonical physics that is taught in schools. If these intuitive concepts are not made clear and consistently addressed through training, research conducted across the natural sciences demonstrates that they have the potential to become ingrained in the minds of individuals and become enduring misconceptions [1]. At the same time, theoretical perspectives emphasize that these alternative ideas are not merely errors but represent coherent explanatory frameworks that can be productively leveraged to support conceptual change [2]. Other conceptions, such as viewing force as a "push that keeps things moving" or confusing heat with temperature, are widespread across educational levels and remarkably resistant to change when teaching is predominantly expository. Comparative evidence indicates that misunderstandings about heat and temperature persist from primary school through secondary education and into university studies, suggesting deep-rooted conceptual difficulties that are not easily resolved by traditional instruction [3]. Recent syntheses that focus specifically on physics indicate that these alternative conceptions are widespread [4]. Therefore, primary education is a crucial window of opportunity during which the early experiential resources of kids can be rearranged in a constructive manner. This is in contrast to the situation in which students are permitted to crystallize into fixed conceptual frameworks that are scientifically deficient.

The evidence that comes from research that involve young infants highlights the intricacy of early thinking about physical occurrences, while at the same time highlighting the fragility of this reasoning. For instance, fine-grained analyses of preschoolers' talk and gestures in tasks on mechanical equilibrium show that children coordinate multiple representational modes as they explore balance situations. This reveals emergent but not yet formalized understandings of force and torque [5]. At the same time, systematic reviews documented that misconceptions about fundamental physics topics, such as mechanics, heat and temperature, and electricity, are already observable in late primary grades. Evidence further indicates that primary students' misconceptions in mechanics are systematically related to their mental age, suggesting that cognitive developmental factors interact with instructional experiences in shaping early physics understanding [6]. These misconceptions may continue into secondary and tertiary education if instruction does not explicitly target conceptual restructuring [1, 4]. In light of these findings, it may be inferred that primary school is not only a preliminary stage for "real" physics learning, but rather a crucial level where instructional design can either scaffold deeper conceptual development or leave naïve explanatory schemes mostly intact.

Over the course of the past few decades, there have been three lines of inquiry that have informed efforts to design more effective physics instruction in the early grades. These lines of inquiry include inquiry-based learning, hands-on experimentation with simple apparatus, and the utilization of digital technologies, such as simulations and robotics. In the context of science education, inquiry-based approaches, in which students are responsible for generating questions, planning and carrying out studies, and interpreting evidence, have been linked to significant improvements in students' scientific knowledge provided they are accompanied by adequate guidance. A seminal meta-analysis conducted by Lazonder and Harmsen [7] highlighted the significance of structured support by revealing that guided inquiry had medium effect sizes on the learning activities, performance, and outcomes of students across all age groups. Recently, a meta-analysis that focused on conceptual comprehension in the fields of science and mathematics discovered that inquiry-based learning has a significant overall benefit ($g = 0.91$), with particularly considerable improvements in open inquiry situations [8]. However, despite the fact that these results are not restricted to primary education or physics, they offer a robust empirical reason for organizing early physics learning around guided inquiry rather than focusing solely on direct instruction.

Within the realm of fundamental physics in particular, comparative research on hands-on vs virtual experimentation has started to shed light on the ways in which various types of practical labor contribute to conceptual comprehension. For example, Evangelou and Kotsis [9] carried out a comparison between pupils in the fifth grade who investigated friction by means of actual apparatus and their colleagues who utilized an analogous virtual environment. They discovered that when both conditions were incorporated into structured inquiry sequences, students in both groups achieved comparable gains in conceptual understanding [9]. This finding suggests that well-designed virtual experiments can, under certain circumstances, complement or even replace physical labs in the primary classroom. When it comes to abstract themes like heat and temperature or electricity, where direct sensory access to crucial variables is limited, other studies indicate that combining physical and virtual labs may be able to harness the benefits of each modality. This is especially true for topics dealing with heat and temperature.

For the purpose of teaching primary physics, the repertoire of tools that are available has been enlarged as a result of parallel improvements in digital technologies. Providing numerous linked representations, supporting real-time data visualization, and creating safe, repeatable circumstances for experimentation are all characteristics that can be achieved through the utilization of digital simulations, data-logging tools, STEM-integrated digital instructional materials, and AI-supported learning environments that offer adaptive scaffolding and automated feedback [10]. Recent work on the use of artificial intelligence in physics education demonstrates that AI-driven tools and lesson designs can further support conceptual understanding by offering adaptive feedback, personalized scaffolding, and dynamic representations tailored to learners' needs. Case-based evidence from one-to-one iPad implementations in primary classrooms shows that digital environments can effectively support students' understanding of energy by enabling representational transformations and iterative exploration of physical processes [11]. When such resources were utilized to frame physics content inside technology-rich problem settings, a study that was conducted in 2023 on STEM-integrated physics digital teaching material found significant gains in students' conceptual understanding as well as new reading skills [12]. At a more general level, recent research has shown that integrating physics education with digital literacy is now an essential component of school science. This is due to the fact that digital technologies have the ability to simultaneously enhance students' conceptual knowledge and improve their skills for a future that is increasingly dominated by technology [13]. The Organization for Economic Cooperation and Development (OECD) has conducted extensive literature reviews, which highlight the fact that access to technology alone does not guarantee learning gains. However, positive effects typically occur when digital tools are tightly integrated with clear learning goals and pedagogical strategies such as guided inquiry [14], a conclusion that is consistent with findings from inquiry-based laboratory work on heat showing significant gains in conceptual understanding and self-efficacy among pre-service teachers [15].

In spite of this mounting body of data, there are still a number of holes. To begin, the findings on hands-on experiments, inquiry-based learning, and digital technologies are frequently discussed in separate literatures. This makes it difficult for researchers and practitioners to form an integrated picture of how these approaches can be combined to support conceptual understanding in primary physics when it comes to the subject matter. Second, a large number of reviews on misconceptions and conceptual change are a synthesis of studies from all levels of education. These reviews provide little visibility into the particular problems and opportunities that are characteristic of primary classrooms [1, 4]. In third place, there is a tendency in certain studies of innovative practices, particularly those that involve digital resources, to place an emphasis on student participation or attitudes, while offering relatively limited evidence about long-term conceptual change.

A vital but somewhat under-reviewed level in physics education research, primary education is the subject of this mini review, which aims to remedy these gaps by concentrating specifically on primary education. The purpose of this project is to compile a compilation of recent empirical data about the teaching of fundamental physics ideas in elementary schools through the use of inquiry-based learning, hands-on experiments, and digital technologies, such as virtual labs and resources that integrate STEM subjects. Over the course of these components, the evaluation places more of an emphasis on outcomes that are associated with conceptual comprehension and the correction of misconceptions than it does on involvement alone. The purpose of this article is to outline design principles for primary physics instruction that can leverage simple apparatus, inquiry processes, and digital tools in complementary ways. This will help young learners construct more coherent and flexible understandings of physical phenomena. This will be accomplished by integrating insights from research traditions that are partially disconnected from one another.

Hands-On Experiments and Inquiry-Based Approaches in Primary Physics

Since the beginning of time, hands-on experiments have been an essential component of science education. This is due to the fact that they enable students to engage directly with physical phenomena, put their ideas to the test, and create explanatory reasoning that is founded on observation and evidence. Simple apparatus, such as ramps, springs, pulleys, thermometers, and reflective surfaces, are widely utilized in fundamental physics to investigate concepts such as force and motion, heat and temperature, and light. These apparatuses are used to investigate these topics frequently. When learners are provided with opportunities to engage with manipulative and experimental setups, research indicates that their engagement grows, and they begin to communicate predictions and explanations in ways that reflect emerging conceptual knowledge rather than merely demonstrating proficiency in the procedures. In the domain of thermal phenomena, hands-on activities with everyday materials have been shown to support primary students in differentiating heat from temperature and in constructing more scientifically appropriate explanations [16]. On the other hand, the manner in which tasks are organized and assisted is a significant factor in determining the effectiveness of hands-on labor for conceptual transformation. Evangelou and Kotsis [9] discovered that students in fifth grade who were studying friction achieved comparable conceptual gains regardless of whether they used real apparatus or a carefully designed virtual environment. This was the case provided that both conditions were embedded in a pedagogically rich sequence that included prediction, observation, and reflection. This finding suggests that the primary mechanisms of conceptual change are not the physical objects themselves, but rather the learners' active engagement with evidence and explanation, a conclusion that is consistent with studies showing that conceptual progress in force depends on how students' alternative ideas are elicited and reorganized across a learning trajectory [17]. Studies of mechanical activities have shown that children who are prompted to defend their predictions and reconcile inconsistencies between anticipation and observation demonstrate greater conceptual reorganization than their classmates who perform hands-on tasks without such reflective prompts. In the context of circular motion, evidence indicates that students who actively perform actions develop more coherent conceptual understanding than those who merely observe demonstrations, highlighting the importance of embodied engagement in early mechanics learning [18]. The findings of this investigation provide credence to the viewpoint that practical experimentation need to be purposefully linked to conceptual reasoning rather than being regarded as an end in and of itself.

Inquiry-based techniques are effective because they structure learning around questions, inquiries, and explanations that are supported by evidence, a process that presupposes adequate levels of scientific literacy among teachers in order to be implemented meaningfully [19]. Recent work further shows that inquiry-based learning in science is strongly supported by mathematical reasoning processes, which scaffold students' critical thinking and enable more coherent evaluation of evidence [20]. These approaches draw on the benefits of hands-on work. In primary school classrooms, it has been demonstrated that guided inquiry sequences are effective in assisting students in progressing beyond intuitive explanations by putting the process of scientific reasoning at the forefront of the learning experience. For instance, when teachers arrange cycles of asking questions, organizing investigations, and evaluating results while paying explicit attention to contradictory ideas, the replies of students begin to demonstrate a movement away from ordinary causal accounts and toward reasoning that is more consistent with scientific principles. There were significant overall effects on conceptual understanding in science and mathematics when inquiry was accompanied by sufficient guidance, according to research conducted by Mediana and colleagues [8] in a meta-analysis of inquiry-based learning. This finding highlights the significance of scaffolding in primary contexts where students may have difficulty meeting the cognitive demands of open-ended exploration. Furthermore, discourse analyses of primary science classrooms reveal that questions posed by teachers that prompt students to justify their answers, compare alternative explanations, and reason based on evidence are strongly associated with the development of more coherent conceptual models by students. This is especially true when instruction explicitly addresses common misconceptions. Therefore, it would appear that instructional sequences that incorporate prediction, assessment, and explanation generate settings in which children are able to confront and modify their concepts that are intuitive.

Nevertheless, research warns against conducting inquiries with only a small amount of guidance. Young learners may experience feelings of being overwhelmed by the demands of organizing and interpreting investigations when assignments are too open or lack explicit help. This can cause them to rely on intuitive explanations or to concentrate on superficial aspects of the job rather than learning the underlying physical principles. For this reason, the successful implementation of inquiry in elementary physics necessitates the careful alignment of task design, the provision of representational support, and the facilitation of the teacher in a manner that leads students toward coherent conceptual reasoning.

Digital Technologies, Virtual Labs, and Robotics in Primary Physics

There is now a wider variety of teaching materials accessible to promote students' engagement with fundamental physics ideas as a result of the increasing integration of digital technologies into primary schools, including not only simulations and virtual laboratories but also material technologies such as 3D printing, which have been shown to enhance primary students' content knowledge, interest in science, and emotional engagement [21]. Children have the opportunity to investigate phenomena that may be difficult to witness directly or isolate physically, such as the interactions between variables in motion, the transfer of heat, or the behavior of light through materials, through the use of digital simulations and virtual laboratories. Evidence from classroom implementations using the software "MATHEMA" to teach light reflection in Grade 5 shows that digital environments can support students in visualizing ray paths, coordinating representations, and constructing more coherent explanations of optical phenomena [22]. Virtual environments can enable conceptual comprehension that is comparable to, or sometimes complements, hands-on experimentation, according to research. This is the case when virtual environments are intelligently created and placed inside guided learning sequences. Computer-based simulations, for instance, have been shown to make invisible variables more accessible by providing real-time visualizations of force vectors or energy flows. This enables students to move beyond perceptual reasoning and toward more abstract conceptual models. These studies were conducted with young learners and were controlled. The affordances of virtual labs, on the other hand, are highly dependent on the instructional context. Learners benefit the greatest from the incorporation of digital tools within structured sequences of prediction, exploration, and reflection, as opposed to the activities being presented as stand-alone activities. In certain circumstances, digital environments can assist in lowering the cognitive burden by isolating particular variables for manipulation. This enables students to concentrate on the underlying causal links without being distracted by the sensory cacophony that is generally associated with physical hardware.

At the same time that virtual laboratories are becoming increasingly widespread in early scientific education, interactive digital technologies that facilitate data collecting and visualization are also being increasingly commonly used. Learners are provided with opportunities to combine their observations with formal representations through the use of motion tracking apps, temperature sensors attached to tablets, and dynamic graphing tools. This helps learners bridge the gap between embodied experience and conceptual thinking. When combined with instructor mediation that establishes a connection between the patterns in the data and scientific conceptions, such as acceleration or thermal equilibrium, digital representations have been shown to be able to enhance students' comprehension, according to research conducted with primary school students who use such tools. In the absence of such mediation, students would focus their attention exclusively on the superficial characteristics of the technology or the aesthetic attractiveness of the interface, which would restrict their prospects for conceptual development.

Emerging as a possible path for engaging young learners with fundamental physics concepts through embodied problem solving is the field of educational robots, which has also emerged as a promising avenue [23, 24]. Findings from studies on circular motion suggest that physically enacting motion patterns leads to deeper conceptual understanding than passive observation, reinforcing the value of embodied interaction in technology-supported physics learning [18]. Providing concrete contexts for the investigation of motion, force, and energy, robots that are designed to negotiate small tracks, respond to inclines, or react to light are becoming increasingly popular. Research conducted in elementary school classrooms suggests that activities involving robotics have the potential to pique students' interest and generate expectations about physical activity. However, the most important factor in achieving conceptual gains is, once again, explicit instruction that establishes a connection between robotic behavior and the laws of physics. Because students are pushed to formulate hypotheses about the motion of a robot and to evaluate and amend their ideas based on information from trials, they begin to build deeper understandings of the physics that lies under the surface. On the other hand, activities that primarily concentrate on coding or robot operation without any conceptual framing may result in high levels of involvement on the part of participants but limited conceptual change.

Across all of these digital and robotics-based interventions, a recurrent theme in the research literature is that technology in and of itself does not guarantee a deeper level of comprehension, a conclusion reinforced by reviews of STEM robotics applications in magnetism, which emphasize the need for strong pedagogical scaffolding [23], as well as by recent evidence showing that AI tools such as ChatGPT can effectively support primary teachers in designing conceptually focused physics experiment worksheets when used with clear pedagogical intent [25, 26]. Rather, the effectiveness of technology is demonstrated when it is utilized to make the reasoning of learners visible, to scaffold explanations, and to mediate dialogue that connects experience with formal concepts. Therefore, digital tools that have been thoughtfully built have the potential to increase the impact of inquiry and hands-on work, providing young students with numerous complimentary pathways so that they can construct coherent and transferable ideas in the field of physics.

Cross-Cutting Themes and Research Gaps

Several themes that help explain both the potential and the constraints of contemporary instructional methods are regularly emerging throughout studies on hands-on experimentation, inquiry-based learning, and digital technologies in basic physics education. These themes help explain both the promise and the limitations of these practices. One of the primary themes is on the significant impact that intuitive thinking has, with studies on energy demonstrating that students' alternative ideas form structured developmental trajectories that can be traced along a learning curve [27]. When it comes to interpreting physical phenomena, young learners frequently rely on perceptual cues or everyday language with research showing that students' misconceptions in mechanics are systematically associated with their mental age, indicating that naïve reasoning patterns are developmentally constrained as well as instructionally shaped [6]. These intuitive ideas tend to shape the way in which children make sense of the results of experiments, digital visualizations, or inquiry sequences. Even in situations when the activities are intended to foster scientific reasoning, children may perceive the results of the activities in a manner that validates rather than challenges their initial notions. This occurs even when the tasks are supposed to assist scientific reasoning. This persistence of daily conceptions is shown across a wide range of issues, including force, heat, temperature, and light with comparative studies demonstrating that misconceptions about thermal phenomena remain strikingly stable across primary, secondary, and tertiary education levels [3]. It is also recorded that this persistence occurs even in classrooms that use active learning methodologies, provided that students' reasoning is not explicitly disclosed and addressed [1]. As a result, numerous studies imply that conceptual change necessitates paying deliberate attention to the underlying explanatory frameworks that children bring to school, rather than concentrating solely on the design of activities, a position consistent with arguments that alternative ideas should be treated as valuable cognitive resources for instruction [2].

The importance that language and representation play in the process of forming students' conceptual knowledge is a second common subject. Analyses of children's trade books about ozone layer depletion reveal that the ozone layer is often represented through metaphors, anthropomorphisms, and simplified causal narratives, which can contribute to the formation of alternative explanatory frameworks prior to formal instruction [28, 29], while studies of traditional fairy tales indicate that misconceptions about natural phenomena are frequently embedded in narrative structures and fantastical explanations [30]. Research on the use of one-to-one iPads in primary physics shows that digital environments can facilitate the coordination of verbal explanations, dynamic visualizations, and symbolic representations in the learning of energy, thereby supporting deeper conceptual restructuring [11]. Representational tools like diagrams, arrows, or digital visualizations have the potential to either clarify or accidentally propagate errors. This is because everyday language frequently carries connotations that are in contradiction with scientific terminology. However, despite the fact that research on early physics learning demonstrates that young students benefit from clear links between physical acts, verbal explanations, and graphical or digital representations, such integration is not always evident in classroom practice. In some instances, digital tools offer representations that are either too abstract or too detailed for primary learners. In other instances, hands-on activities may not provide adequate representational scaffolding to facilitate generalization beyond the activity that is now being performed. The results of this study are consistent with broader research that demonstrates that conceptual advances can only be achieved through the intentional support of representational fluency.

The dynamic relationship that exists between theoretical comprehension and active participation is the third main theme, with research on kinaesthetic teaching of impulse showing that active bodily engagement can substantially improve the quality of students' reasoning [31]. Although numerous studies have reported high levels of enjoyment and participation in activities that involve hands-on work, inquiry, or the use of technology, it is important to note that such engagement does not inevitably result in a shift in conceptual understanding. In the absence of systematic chances to articulate predictions, compare explanations, or review ideas over time, learning frequently remains rooted in the present moment and fails to influence long-term comprehension. In primary physics studies, the distinction between procedural success and conceptual thinking is brought up on multiple occasions. This underscores the necessity of instructional designs that put an emphasis on explanation and evidence rather than on the completion of activities.

According to the study landscape, there are various gaps, despite the fact that consistent findings have been found across these themes. One of the most significant gaps is the absence of longitudinal studies that monitor the development of conceptual knowledge throughout the primary years and into the early secondary education years. It is difficult to evaluate if conceptual benefits are long-lasting or transferable to new contexts because a significant portion of the work that has been done thus far relies on brief interventions that are topic-specific. The integration of digital technologies in primary physics is a second area of research that is lacking. Although numerous studies have highlighted the favorable effects of this integration, very few studies have investigated the mechanisms by which simulations, robots, or digital representations either assist or hinder conceptual transformation. Given the current efforts being made on a global scale to include digital literacy into science education frameworks, this is of utmost importance [13]. Pedagogical content knowledge and teacher knowledge constitute the third research gap that has to be addressed, particularly given evidence that teachers' readiness and intention to utilize educational robotics in early years education varies considerably and is shaped by beliefs and perceived competence [24, 32]. It has been found that many primary school teachers have a low level of confidence when it comes to teaching physics. Studies have shown that their own intuition notions may influence how they frame experiments, how they guide inquiry, or how they perceive the thinking of their students. However, a relatively small amount of research has been conducted to investigate how professional development might best assist educators in ensuring that young students experience conceptual transformation.

In general, the body of research suggests that elementary physics education would be improved by the implementation of more integrated research designs that connect cognitive, pedagogical, and technical points of view. Future study could give better evidence for developing learning environments that encourage long-lasting and transferable conceptual knowledge in physics by examining how children's intuitive notions interact with various instructional tools and representations over time. This could be accomplished by examining how children respond to these interactions over time.

Implications for Teaching and Teacher Preparation

The findings of the research that is discussed in this article have important repercussions for the development of primary physics curricula as well as for the training of teachers who are responsible for putting such policies into practice. Based on the findings of research conducted on hands-on experiments, inquiry-based learning, and digital technologies, one of the most important takeaways is that it is not possible to assume that students have conceptual comprehension simply because they have "done" an activity or because they report enjoying or engaging with it. In primary physics instruction, the primary focus should be on eliciting, confronting, and restructuring the intuitive notions of the students, rather than primarily focusing on the completion of activities or the fluency of procedures. For those who are responsible for designing educational programs, this realization translates into the necessity of sequencing learning experiences in a manner that revisits fundamental ideas throughout grades, beginning with everyday thinking and progressing toward higher levels of formalized comprehension, a design principle supported by research showing that understanding of energy develops along identifiable learning curves shaped by students' alternative ideas [27]. Students are able to integrate their perceptual experiences with abstract concepts through the use of sequential exercises that move them from prediction to evidence interpretation to explanation. This is a vital component for a long-term comprehension of physical processes.

In light of the fact that primary school teachers are frequently generalists with a limited formal experience in physics, teacher training appears to be a crucial lever for promoting conceptual development [19], particularly given evidence that many primary teachers hold ambivalent or hesitant attitudes toward experimentation in physics [33]. Comparative evidence from Greek pre-service teachers and primary school students indicates that scientific literacy levels are closely aligned, suggesting that limitations in teachers' epistemic preparation may be mirrored in students' understanding of science concepts [34]. Another empirical evidence from Greek pre-service primary teachers shows that efficacy beliefs in physics teaching vary considerably and are strongly associated with confidence in using inquiry-oriented and conceptually demanding approaches, highlighting self-efficacy as a key mediator of instructional quality [35]. According to research, the way in which teachers frame questions, assess student thinking, and respond to learners' explanations might be influenced by their own intuitive assumptions about force, heat, or motion, with evidence from Greek primary teachers showing systematic relationships between self-concept, years of service, and alternative conceptions of force and weight [36]. This is particularly important in the context of educational robotics, as studies show that teachers' intentions to adopt such technologies in preschool and primary education are strongly shaped by perceived pedagogical value and self-efficacy [24]. It is possible that instructional efforts will accidentally perpetuate the same misunderstandings that they are attempting to overcome if pre-service and in-service teachers are not provided with the assistance necessary to build strong topic knowledge and pedagogical content knowledge in the subject of physics. Therefore, chances for instructors to investigate frequent misunderstandings, to reflect on their own reasoning, and to practice facilitating activities that make student thinking transparent and subject to evidence-based discussion should be included in high-quality professional development, particularly in light of recent findings that artificial intelligence can assist primary teachers not only in generating worksheets but also in planning and executing physics classroom experiments in pedagogically coherent ways [26]. Case studies, lesson studies, and collaborative analysis of classroom discourse have all demonstrated that they have the potential to assist educators in interpreting the emerging explanations of their students and adapting their teaching approaches accordingly.

Pedagogical framing is required in order to successfully integrate digital and robotics technologies into primary physics programming, a point reinforced by bibliographic evidence showing that teachers' attitudes and methodological choices play a decisive role in the effective use of educational robotics in primary classrooms [37], and by studies indicating that preschool and primary educators' perceptions of robotics in STEM strongly influence their willingness to integrate such tools into everyday teaching [32]. Technology should not be introduced as an extra or a novelty; rather, digital tools should be incorporated into instructional sequences that put an emphasis on explanation, representation, and translation across different settings. Digital simulations or interactive apps, when combined with cycles of prediction, observation, and explanation, have the potential to assist students with seeing and testing correlations between variables that would otherwise be concealed, as evidenced in teaching scenarios using the MATHEMA software to support primary students' reasoning about light reflection [22]. In a similar vein, educational robots can offer embodied contexts for the investigation of motion and force; however, this is only possible when assignments explicitly link robot behavior to physical principles and when teachers scaffold students' reasoning about cause and effect.

The practices of assessment are an essential component in the process of facilitating conceptual change. When compared to typical quizzes, which place a greater emphasis on correct answers, formative evaluations that probe students' explanations, enable comparisons of alternative concepts, and track progress over time are more likely to reveal persisting misconceptions. Teachers can gain meaningful insights into the reasoning trajectories of their students by using concept inventories that have been tailored for primary learners, open-ended explanation prompts, and structured reflection notebooks. Schools have the ability to establish learning environments that develop meaningful and transferable physics understanding from the earliest grades onward by aligning the curriculum, instruction, and evaluation around deep conceptual engagement rather than surface-level achievement.

Conclusions

Despite the fact that primary education plays a crucial role in influencing how children comprehend physical phenomena, research regularly demonstrates that children's intuitive perceptions of force, motion, heat, temperature, energy, and light remain highly durable throughout the early years of their lives. Despite the fact that young students approach physics with a feeling of wonder and a strong desire to make sense of the world around them, the explanations that they provide are frequently based on their own perceptual experiences and the language that they use in everyday life rather than on scientific principles with evidence indicating that such naïve explanatory frameworks in mechanics are closely linked to students' cognitive developmental level [6, 38]. Because of this, primary school is an essential time for facilitating the gradual restructuring of intuitive notions into conceptual frameworks that are more cohesive and transferable particularly in light of evidence showing that many students enter secondary education with largely unchanged alternative conceptions of basic physics ideas [39]. Evidence from hands-on experimentation, guided inquiry, and digital technologies reveals that each method has the potential to promote conceptual comprehension; however, this potential can only be realized when the method is executed with pedagogical intentionality. Experiments need to be incorporated into structured sequences that prompt prediction, observation, and explanation; inquiry activities need to have clear guidance in order to prevent cognitive overload; and digital tools need to be integrated in a manner that highlights causal mechanisms rather than offering surface-level interactivity [8, 9].

Engagement on its own is not adequate for conceptual transformation, according to the literature, which conveys this message in a consistent manner. Even if the lesson does not explicitly address alternate explanations and does not give representational assistance, young learners can nevertheless enjoy hands-on activities or digital simulations while still retaining their initial notions. Therefore, findings that span across multiple domains highlight the significance of purposeful scaffolding, rich classroom discourse, and assessment techniques that make student thinking visible and open to change. Additionally, the amount of opportunities for students to expand their conceptual understanding is substantially impacted by the teachers' own comprehension of physics ideas as well as their confidence in their ability to facilitate inquiry-oriented courses, a relationship that is also evident in studies of educational robotics, where teachers' attitudes and methodological orientations shape the quality of implementation [37]. There is a need for professional learning that integrates pedagogical content knowledge, physics content knowledge, and skills for interpreting student reasoning, according to studies in teacher education [35]. These studies indicate that primary teachers may unknowingly reinforce misconceptions if they do not receive targeted support.

The long-term development of conceptual understanding during the primary years should be investigated in future study, as should the ways in which mixtures of hands-on activities, inquiry, and digital technologies might promote change that is long-lasting. Additionally, there is a need for increased attention to be paid to the mechanisms by which digital and robotics-based tools change the reasoning of learners. This is especially important in light of the growing integration of technology into everyday education in schools. This review highlights the fact that effective primary physics education is dependent less on the novelty of technologies and more on coherent pedagogical design. This is accomplished by bringing together evidence from a variety of educational traditions. When learners' intuitive ideas are treated as productive starting points for reasoning rather than obstacles to overcome, and when instructional approaches are aligned around explanation and evidence, primary classrooms have the potential to become powerful environments for the development of a long-lasting understanding of the physical world, especially when educators are aware of and critically engage with the representations of science that children encounter in books and media [29].

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