Augmented reality as a pre-practice pedagogical tool in children's motor skill learning: a theoretical systematic review for physical education and swimming instruction

La realidad aumentada como herramienta pedagógica previa a la práctica en el aprendizaje de habilidades motrices infantiles: una revisión sistemática teórica para la educación física y la enseñanza de la natación

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Abstract

Background: Augmented reality (AR) has increasingly been used in education, yet its role in children's motor skill learning remains insufficiently theorized. In physical education and swimming instruction, children must understand movement sequences, body orientation, timing, breathing, and coordination before performing skills in real practice settings. Therefore, AR should be examined not only as a digital innovation, but also as a pre-practice pedagogical tool that supports movement understanding before physical execution.
Objective: This theoretical systematic review synthesizes existing literature on AR in children's motor skill learning, physical education, and swimming instruction to develop a conceptual framework explaining how AR supports pre-practice learning.
Methods: Following PRISMA 2020 guidelines, relevant studies published between 2014 and 2026 were identified from Scopus, Web of Science, ERIC, SPORTDiscus, PubMed, and Google Scholar. Thematic synthesis was applied to identify the pedagogical mechanisms through which AR supports movement learning.
Results: Five cross-cutting themes emerged: AR as visual-motor representation, cognitive scaffolding, cognitive load regulation, motivational readiness, and embodied transfer from digital visualization to physical execution. These themes form the proposed AR-Based Pre-Practice Pedagogical Continuum, which positions AR as a bridge between seeing, understanding, readiness, and doing.
Conclusions: AR should be understood as a pedagogical support system rather than a replacement for physical practice, teacher feedback, or embodied movement experience. In swimming instruction, AR may help children prepare for complex technical components before entering the pool. Future research should test this framework through experimental designs, retention assessment, and transfer-based evaluation.

Keywords

Augmented reality; motor skill learning; physical education; swimming instruction; children; theoretical systematic review.

Resumen

Antecedentes: La realidad aumentada (RA) se ha utilizado cada vez más en la educación; sin embargo, su papel en el aprendizaje de habilidades motrices infantiles aún requiere mayor fundamentación teórica. En educación física y enseñanza de la natación, los niños deben comprender secuencias de movimiento, orientación corporal, ritmo, respiración y coordinación antes de ejecutar habilidades en contextos reales. Por ello, la RA debe entenderse como una herramienta pedagógica previa a la práctica que favorece la comprensión del movimiento antes de la ejecución física.
Objetivo: Esta revisión sistemática teórica sintetiza la literatura sobre RA en el aprendizaje de habilidades motrices infantiles, educación física y enseñanza de la natación, con el fin de desarrollar un marco conceptual que explique su función en el aprendizaje previo a la práctica. Métodos: Siguiendo PRISMA 2020, se analizaron estudios publicados entre 2014 y 2026 en Scopus, Web of Science, ERIC, SPORTDiscus, PubMed y Google Scholar. Se aplicó una síntesis temática para identificar mecanismos pedagógicos asociados al aprendizaje motor.
Resultados: Surgieron cinco temas: representación visomotriz, andamiaje cognitivo, regulación de la carga cognitiva, preparación motivacional y transferencia encarnada desde la visualización digital hacia la ejecución física. Estos temas conforman el Continuo Pedagógico Previo a la Práctica basado en RA.
Conclusiones: La RA debe entenderse como apoyo pedagógico, no como reemplazo de la práctica física ni de la retroalimentación docente. En natación, puede preparar a los niños para componentes técnicos complejos antes de ingresar a la piscina.

Palabras clave

Realidad aumentada; aprendizaje motor; educación física; enseñanza de la natación; niños; revisión sistemática teórica.

Introduction

Augmented reality (AR) has gained increasing attention in educational research because it enables digital objects, visual information, and interactive representations to be integrated into real-world learning environments. Unlike conventional digital media, AR does not detach learners from their immediate physical context; rather, it enriches that context by adding visual and spatial information that can support observation, interpretation, and learning. Previous reviews have shown that AR may improve learning achievement, engagement, and the representation of complex content, although its effectiveness depends on usability, instructional design, and the management of cognitive load (Akçayır & Akçayır, 2017; Buchner et al., 2022).

In physical education, the pedagogical value of augmented reality is especially relevant because learning involves not only conceptual understanding but also bodily action. Children must observe, interpret, and perform movement patterns while coordinating perception, cognition, motivation, and physical execution. Motor competence is an important foundation for participation in physical activity and sport, and structured physical education interventions can support its development (Lorås, 2020; Pratama et al., 2025). However, children often experience difficulty when learning complex movement skills that require the simultaneous coordination of several body segments, particularly when instruction relies mainly on verbal explanation, teacher demonstration, static images, or video-based modeling.

Observation before practice is an important component of motor learning. A systematic review by Han et al. (2022) showed that observational learning can support motor skill development in physical education across different learning levels. This suggests that how learners see, understand, and mentally organize movement before execution may influence the quality of later performance. AR may extend the pedagogical value of observation by allowing learners to view movement phases repeatedly, focus on specific technical elements, and connect visual information with later physical practice.

These issues are particularly important in swimming instruction. Swimming requires children to coordinate body alignment, arm action, leg movement, breathing rhythm, and whole-body control in an aquatic environment. Compared with many land-based skills, swimming also involves buoyancy, water resistance, breath control, and psychological readiness. For beginner learners, the pool environment can increase uncertainty and make it difficult to process technical instructions during practice. Therefore, children may benefit from pre-practice learning support that helps them understand movement sequences before entering the water.

In swimming instruction, motor learning cannot be understood only as the acquisition of sport-specific techniques such as front crawl, backstroke, breaststroke, or butterfly. Before children learn formal swimming strokes, they need to develop aquatic readiness and basic aquatic motor competence. Aquatic readiness refers to the learner's gradual adaptation to the aquatic environment through the development of basic aquatic motor skills, which later become the foundation for more specific swimming techniques, starts, and turns. This distinction is important because learning to swim involves not only reproducing technical movements but also adapting perception, posture, breathing, balance, and coordination to the properties of water. The World Aquatics teaching reference manual explains that adaptation to the aquatic environment is a teaching-learning process through which learners acquire basic aquatic motor skills before progressing toward specific aquatic motor skills (Barbosa et al., 2021).

For children, aquatic motor learning is especially complex because the water environment changes the usual relationship between the body, movement, and balance. On land, children can rely on stable support surfaces and familiar postural control. In water, however, buoyancy, drag, immersion, breath regulation, and body orientation create additional perceptual and motor demands. As a result, beginner learners must coordinate technical movement while simultaneously learning how to float, control breathing, maintain horizontal body alignment, and manage emotional responses to the aquatic environment. Recent work on fear of the aquatic environment also emphasizes that fear, uncertainty, and low perceived competence can influence children's willingness to participate and their learning process in swimming contexts (Coelho et al., 2025; Ostrowski et al., 2022).

Although AR has been examined in education, physical education, and motor learning, the existing evidence remains fragmented across different disciplinary and pedagogical contexts. Previous reviews have generally discussed AR in broad educational settings, focusing on learning achievement, motivation, usability, cognitive load, or implementation challenges. Other studies in physical education have shown that AR may support motivation, spatial understanding, motor learning, and learning outcomes, including in technology-assisted and mobile AR-based physical education contexts (Faruk et al., 2025; Festiawan et al., 2025). However, these reviews have not sufficiently explained how AR can function as a pre-practice pedagogical tool for children's motor skill learning, particularly in swimming instruction.

This gap is important because children's swimming learning requires more than exposure to digital content or general physical education activities. It requires the integration of visual understanding, cognitive organization, emotional readiness, and embodied movement preparation before entering the aquatic environment. To date, limited theoretical synthesis has connected AR-based visualization, observational learning, cognitive scaffolding, cognitive load regulation, motivational readiness, and embodied transfer within a single framework for children's aquatic motor learning. Therefore, this review addresses a specific conceptual gap by explaining how AR may operate as a preparatory bridge between seeing, understanding, and doing in children's physical education and swimming instruction.

A theoretical systematic review is therefore appropriate for this topic. Unlike a narrative review, which primarily describes and discusses literature broadly, a theoretical systematic review uses systematic procedures to identify, organize, and synthesize evidence while also developing conceptual explanations from the reviewed studies. In this review, AR is not positioned as a replacement for physical practice, teacher feedback, or real movement experience. Instead, it is conceptualized as a preparatory pedagogical tool that may support children's movement visualization, cognitive scaffolding, cognitive load regulation, motivational readiness, and transition toward embodied motor performance.

Accordingly, this theoretical systematic review aims to synthesize literature on augmented reality in children's motor skill learning, physical education, and swimming instruction. Specifically, it seeks to explain how AR may support pre-practice readiness by helping children see, understand, and organize movement before physical execution. The main contribution of this review is the development of a theoretical framework that positions AR as a pedagogical bridge between digital visualization and embodied motor learning in children's physical education and swimming contexts.

Theoretical Framework

Augmented Reality as a Pre-Practice Pedagogical Tool

Augmented reality can be defined as a technology that overlays virtual objects or digital information onto the real world, allowing virtual and physical elements to appear within the same learning space. In education, this feature gives AR the capacity to make learning objects more visible, interactive, and contextually connected to the learner's environment (Akçayır & Akçayır, 2017). In physical education, this is especially meaningful because learning often depends on the ability to connect visual information with bodily action.

In this review, AR is conceptualized as a pre-practice pedagogical tool. This means that AR supports the stage before physical execution, when children are still forming an understanding of what the movement looks like, how its phases are organized, and how different body parts should work together. Pre-practice learning is not a substitute for real movement practice. Rather, it prepares children to enter practice with clearer mental representations, better attention to key movement cues, and greater confidence in what they are expected to perform.

This position is particularly relevant for swimming instruction. Before children can perform front crawl or breaststroke, they must understand the sequence and coordination of body alignment, leg action, arm movement, breathing, and rhythm. If these elements are introduced only during pool practice, children may be required to process too much information while also adapting to the aquatic environment. AR may help address this challenge by allowing children to observe technical phases in advance, revisit them repeatedly, and enter the pool with stronger visual-cognitive preparation.

Motor Learning and Observational Preparation

Motor learning involves changes in the ability to perform movement skills as a result of practice, experience, feedback, and refinement. In children's physical education, this process begins before execution.

Children first need to observe, interpret, and mentally organize the movement they are expected to perform. Observational learning is therefore an important pedagogical mechanism in PE, as it allows learners to construct internal representations of motor actions before attempting them physically.

A systematic review by Han et al. (2022) showed that observational learning can support motor skill development in physical education across learning levels. This finding is important for AR-based instruction because AR can be understood as an enhanced form of observational support. Instead of relying only on live demonstration, AR may allow children to observe movement phases repeatedly, focus on specific technical elements, and connect visual information with later practice.

In swimming, observational preparation is essential because technical errors often occur when learners do not clearly understand the timing or sequence of movement phases. For example, children may kick without maintaining body alignment, move the arms without breathing coordination, or lift the head in ways that disrupt body position. AR can theoretically support motor learning by making these relationships more visible before children attempt the skill in water.

Cognitive Theory of Multimedia Learning

The cognitive theory of multimedia learning provides a strong theoretical basis for AR-based instruction. Mayer (2014) explains that learners process information through visual/pictorial and auditory/verbal channels, but each channel has limited capacity. Meaningful learning occurs when learners select relevant information, organize it into coherent mental representations, and integrate it with prior knowledge. Instructional materials should therefore be designed to reduce irrelevant processing, manage essential processing, and stimulate meaningful cognitive engagement.

This theory is highly relevant to AR in children's motor skill learning. Movement skills often require learners to process verbal cues and visual demonstrations at the same time. If explanations are too abstract or demonstrations are too fast, children may fail to identify the essential features of the movement. AR may support multimedia learning by combining visual movement representations with simple verbal cues, labels, prompts, or guided sequences.

In swimming instruction, for example, AR may present a breathing phase together with a short cue such as "turn," "inhale," and "return," or show the relationship between arm pull and body rotation. Such integration can help children connect technical vocabulary with observable movement patterns. However, the same theory also warns that AR must be designed carefully. Too many animations, labels, sounds, or visual effects may overload children's limited processing capacity and reduce learning quality.

Cognitive Load Theory and Movement Complexity

Cognitive load theory is central to understanding why AR may be helpful before physical practice. Children learning a new motor skill must process multiple sources of information at once: teacher instructions, visual demonstrations, body sensations, environmental conditions, and performance feedback. When the learning task is complex, this demand can exceed the learner's cognitive capacity.

Buchner et al. (2022) showed that AR can have mixed effects on cognitive load and performance. AR may reduce cognitive load when it clarifies information and makes abstract content more concrete, but it may increase cognitive load when the interface is difficult to use or when the learning material contains too much visual information. Therefore, AR should not be assumed to be automatically effective; its effectiveness depends on instructional design, sequencing, and learner support.

In swimming instruction, cognitive load is especially high because the child must coordinate technical information while adapting to water. A beginner may be asked to maintain body position, kick correctly, move the arms, breathe at the right moment, and stay calm in the pool. AR-based pre-practice learning can theoretically reduce this burden by separating the understanding stage from the execution stage. Children can first study movement phases outside the pool, then apply them gradually in water-based practice.

Cognitive Scaffolding in Children's Motor Skill Learning

Scaffolding refers to instructional support that helps learners perform tasks they cannot yet complete independently. In movement learning, scaffolding may include demonstrations, visual cues, task simplification, feedback, and guided practice. AR can function as cognitive scaffolding because it can break complex motor skills into smaller, clearer, and more manageable phases.

Ibáñez & Delgado-Kloos (2018) reported that AR learning environments often support exploration and simulation, but they also emphasized that future AR learning applications need stronger metacognitive scaffolding and learning support. This point is important for physical education because simply showing a digital model is not enough. Children need structured guidance that helps them understand what to observe, why it matters, and how it relates to later movement execution.

For swimming, AR-based scaffolding may involve separating the technique into body position, leg action, arm action, breathing, and whole-body coordination. Each phase can be introduced visually and progressively before being integrated into full movement. This approach may help children avoid the common problem of treating swimming technique as one difficult whole. Instead, they can understand the skill as a sequence of connected components.

Motivation, Engagement, and Readiness to Learn

Motivation is an important factor in children's physical education because attention, persistence, and willingness to practice are influenced by how meaningful and enjoyable the learning experience feels. AR has been widely discussed as a tool that can increase engagement because it provides interactive and visually attractive learning experiences. In physical education, Moreno-Guerrero et al. (2020) reported positive effects of AR-based teaching, including improvements related to motivation in physical education learning.

A recent meta-analysis by Prasetya et al. (2024) also found that AR learning experiences had positive effects on motivational dimensions, including attention, relevance, confidence, and satisfaction. Although this evidence comes from broader educational contexts rather than swimming specifically, it supports the argument that AR may help create stronger learner readiness before practice.

In swimming instruction, readiness is not only cognitive but also emotional. Children who feel uncertain or anxious may be less willing to participate fully in pool-based practice. AR may help by making the upcoming task more familiar before direct exposure to water. When children can see and rehearse the logic of movement in advance, they may enter the practice setting with greater confidence and lower uncertainty.

Embodied Learning: From Digital Visualization to Bodily Performance

Physical education is fundamentally embodied. Children do not learn movement only by receiving information; they learn through perception, action, correction, and bodily experience. For this reason, AR should not be interpreted as a replacement for real physical practice. Its pedagogical value lies in supporting the transition from digital visualization to embodied performance.

The theoretical link between AR and embodied learning can be explained through the idea that visual representations prepare the learner for action. When children observe movement phases through AR, they begin to anticipate how the movement should feel and how their bodies should be organized. This is especially important in swimming because children must eventually adapt their movement to buoyancy, water resistance, breathing rhythm, and body control in the pool.

Thus, AR can be positioned as a bridge between external representation and bodily execution. It supports the "seeing" and "understanding" stages before the "doing" stage. In this framework, effective AR-based instruction should always be connected to real practice, teacher feedback, and progressive skill refinement.

Proposed AR-Based Pre-Practice Framework

Based on the theoretical synthesis above, this review proposes an AR-based pre-practice framework for children's motor skill learning. The framework explains how AR may support physical education and swimming instruction through five connected mechanisms: visual-motor representation, cognitive scaffolding, cognitive load regulation, motivational readiness, and embodied transfer.

The proposed AR-based pre-practice pedagogical continuum positions AR as a bridge between digital visualization and embodied motor performance. Rather than replacing direct practice, AR is conceptualized as a preparatory learning layer that supports children's visual understanding, cognitive organization, confidence, and readiness before physical execution. Figure 1 illustrates this conceptual model and anchors the theoretical direction of the review.

Figure 1. AR-Based Pre-Practice Pedagogical Continuum in Children's Motor Skill Learning

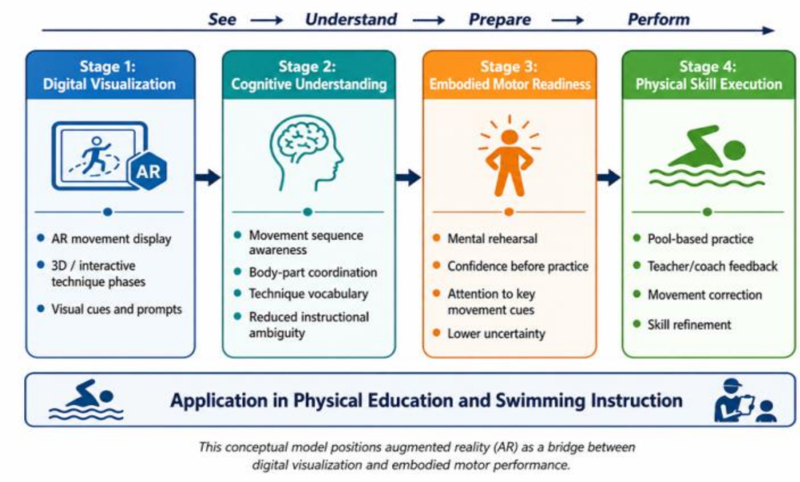


Figure 1 visualizes the proposed conceptual continuum of augmented reality as a pre-practice pedagogical tool. The model explains how AR may support children's movement learning by connecting digital visualization, cognitive understanding, embodied readiness, and physical skill execution. In swimming instruction, this continuum is particularly relevant because learners must understand body position, arm action, leg movement, breathing, and whole-body coordination before performing the skill in an aquatic environment.

Table 1.

Component	Theoretical Function	Application in Swimming Instruction
Visual-motor representation	Makes movement phases visible and easier to observe	Showing body position, arm action, leg movement, breathing, and rhythm
Cognitive scaffolding	Breaks complex skills into smaller learning units	Presenting front crawl and breaststroke in step-by-step phases
Cognitive load regulation	Reduces confusion before direct practice	Allowing children to understand technique before entering the pool
Motivational readiness	Increases attention, confidence, and interest	Making pre-practice learning more interactive and less intimidating
Embodied transfer	Connects digital visualization with physical execution	Preparing children to perform coordinated movement in water

This framework positions AR as a pedagogical bridge between seeing, understanding, and doing. In children's swimming instruction, this bridge is important because learners must first understand complex movement relationships before they can perform them effectively in water. The contribution of AR is therefore not limited to technological innovation; it lies in its capacity to prepare learners cognitively, visually, and motivationally for embodied motor practice.

Method

Design, Search Strategy, and Eligibility Criteria

This study employed a theoretical systematic review design guided by the PRISMA 2020 framework. PRISMA 2020 was used to ensure transparency in the process of identifying, screening, assessing eligibility, and including studies in the final synthesis. The PRISMA 2020 statement provides updated reporting guidance for systematic reviews and includes a 27-item checklist and flow diagram templates for documenting study selection procedures (Page et al., 2021).

Unlike a meta-analysis, this review did not aim to statistically pool effect sizes. Instead, it synthesized conceptual and empirical evidence to develop a theoretical explanation of how augmented reality (AR) may function as a pre-practice pedagogical tool in children's motor skill learning, physical education, and swimming instruction. The review therefore combined systematic searching with thematic synthesis to identify recurrent pedagogical mechanisms, theoretical patterns, and research gaps across the included literature.

In this study, the term theoretical systematic review refers to a review approach that combines transparent systematic procedures with theory-oriented interpretation. It differs from a narrative review because the literature was not selected or discussed broadly based on author preference, but was identified through explicit database searching, eligibility criteria, screening, quality appraisal, data extraction, and synthesis procedures. It also differs from a purely conceptual synthesis because the theoretical framework developed in this review was grounded in systematically identified and appraised sources. Thus, the review was both systematic in its evidence-selection process and theoretical in its purpose of developing an explanatory framework for AR-based pre-practice learning in children's motor skill and swimming instruction.

A systematic search was conducted across six electronic databases: Scopus, Web of Science, ERIC, SPORTDiscus, PubMed, and Google Scholar. These databases were selected because they cover multidisciplinary literature in education, physical education, sport science, health, and learning technology. The search was limited to peer-reviewed publications published between 2014 and 2026, considering the rapid development of AR technology in educational research over the last decade.

Search terms were organized into four concept clusters: (1) augmented reality and learning technology; (2) physical education and sport learning; (3) motor skill learning and movement competence; and (4) children and swimming instruction. The main Boolean search string was:

> ("augmented reality" OR "AR" OR "mobile augmented reality" OR "AR-based learning") AND ("physical education" OR "sport learning" OR "movement learning" OR "motor skill learning" OR "motor competence") AND ("children" OR "students" OR "school-aged learners" OR "young learners") AND ("swimming" OR "aquatic skill" OR "sport skill" OR "technique instruction")

Additional searches were conducted using narrower combinations, including:

"augmented reality" AND "physical education"

"augmented reality" AND "motor skill learning"

"augmented reality" AND "sport learning"

"augmented reality" AND "children" AND "movement learning"

"augmented reality" AND "swimming instruction"

"augmented reality" AND "cognitive load" AND "learning"

The search strategy was intentionally broad because research on AR in swimming instruction remains limited. Therefore, studies from physical education, sport pedagogy, motor learning, and educational technology were included when they provided theoretical or empirical relevance to AR-supported movement learning.

PICOS Framework

The parameters for literature inclusion and exclusion were structured using the PICOS framework: Population, Intervention, Comparison, Outcomes, and Study design. This framework helped ensure that the selected studies were directly relevant to AR-supported motor skill learning in children and school-based or sport-learning contexts.

Table 2. PICOS Framework for Study Eligibility

Criterion	Specification
Population (P)	Children, students, school-aged learners, or young sport learners involved in physical education, sport learning, motor skill learning, or swimming-related instruction
Intervention (I)	Augmented reality-based instruction, AR-supported learning media, mobile AR applications, AR-based visualization, or AR-supported pre-practice learning
Comparison (C)	Conventional instruction, teacher demonstration, video-based learning, non-AR digital media, no intervention, or conceptual comparison across instructional approaches
Outcomes (O)	Motor skill learning, movement understanding, technique comprehension, motivation, engagement, cognitive load, confidence, pre-practice readiness, skill performance, or transfer to physical execution
Study designs (S)	Quantitative, qualitative, mixed-methods, quasi-experimental, experimental, design-based, R&D, and theoretical or conceptual studies directly related to AR-supported movement learning

This PICOS structure ensured that the review did not merely collect general AR studies, but focused on literature that could explain how AR supports the transition from digital visualization to embodied motor performance.

Inclusion and Exclusion Criteria

Studies were included in this review if they were published between 2014 and 2026, appeared in peer-reviewed journals or reputable academic proceedings, and were written in English. Eligible studies had to focus on augmented reality in education, physical education, sport learning, motor skill learning, or movement-based instruction. Studies were also required to involve children, students, school-aged learners, sport learners, or educational users whose learning context was relevant to movement learning. In addition, the studies had to report learning outcomes or provide theoretical insights related to movement understanding, skill acquisition, engagement, motivation, cognitive load, instructional design, or pre-practice learning. Only studies that provided sufficient methodological or conceptual detail for thematic synthesis were retained.

Studies were excluded if they focused solely on virtual reality without addressing augmented reality, or if they discussed AR only from a technical or engineering perspective without clear educational, pedagogical, or motor learning relevance. Studies were also excluded when they focused exclusively on elite competitive sport performance without connection to instruction, learning, or pedagogy. Clinical, therapeutic, and rehabilitation studies were not included unless they had a clear relationship with education or motor skill learning. Editorials, opinion papers, news articles, non-peer-reviewed grey literature, duplicate records, and studies unavailable in full text were also excluded. Systematic reviews and meta-analyses were not treated as primary empirical evidence in the synthesis; however, they were used to support the theoretical background, methodological justification, and interpretation of broader research trends when directly relevant to augmented reality, motor learning, or physical education.

AR Pre-Practice Pedagogical Coding Matrix

Instead of using cultural context coding as in the model article, this review used an AR Pre-Practice Pedagogical Coding Matrix. This coding matrix was developed to classify how each included study positioned AR in relation to children's movement learning, cognitive preparation, and physical skill execution.

Table 3. AR Pre-Practice Pedagogical Coding Matrix

Code	Label	Characteristics	Example Application
AR-P1	Visual-Motor Representation	AR is used to display movement phases, spatial orientation, body position, or technique sequences	Showing body alignment, arm trajectory, leg movement, or breathing phase
AR-P2	Cognitive Scaffolding	AR breaks complex movement skills into smaller, structured learning units	Presenting front crawl or breaststroke in step-by-step phases
AR-P3	Cognitive Load Regulation	AR simplifies complex instructional information or reduces ambiguity before practice	Allowing children to understand movement outside the pool before execution
AR-P4	Motivational Readiness	AR increases attention, engagement, confidence, or willingness to participate	Making pre-practice learning more interactive and less intimidating
AR-P5	Embodied Transfer	AR supports the transition from visual understanding to real movement execution	Applying AR-learned movement cues during pool-based or field-based practice

This coding matrix provided the main analytical structure for identifying how AR may operate as a pre-practice pedagogical tool. Coding was performed at the level of study aims, intervention characteristics, learning outcomes, and theoretical implications. Where a study addressed more than one pedagogical function, multiple codes were assigned.

Data Extraction

Data were extracted using a standardized data extraction form. The extracted information included bibliographic details, study context, participant characteristics, AR application type, learning domain, target skill, theoretical orientation, outcome measures, key findings, limitations, and relevance to the AR pre-practice framework.

Table 4. Data Extraction Framework

Extracted Component	Description
Author and year	Name of author(s) and publication year
Country/context	Country or educational context of the study
Study design	Experimental, quasi-experimental, qualitative, mixed-methods, R&D, theoretical, or review
Participants	Children, students, teachers, coaches, or sport learners
Learning context	Physical education, sport learning, motor skill learning, swimming, or movement-based learning
Type of AR	Mobile AR, marker-based AR, markerless AR, 3D visualization, AR simulation, or AR application
Target skill/content	Motor skill, sport technique, movement competence, swimming technique, spatial learning, or body coordination
Theoretical basis	Motor learning, multimedia learning, cognitive load, scaffolding, embodied learning, motivation, or instructional design
Main findings	Learning outcomes, engagement, motivation, cognitive effects, skill performance, or implementation issues
Relevance to framework	AR-P1, AR-P2, AR-P3, AR-P4, AR-P5
Limitations	Methodological, technological, sample, measurement, or implementation limitations

Two reviewers independently screened titles, abstracts, and full texts. Disagreements were resolved through discussion and consensus. If disagreement remained, a third reviewer was consulted. This procedure was used to reduce selection bias and strengthen the reliability of study inclusion.

Quality Appraisal

The methodological quality of included empirical studies was assessed using the Mixed Methods Appraisal Tool (MMAT) version 2018. The MMAT is designed to appraise qualitative, quantitative, and mixed-methods studies within systematic reviews that include diverse types of evidence (Hong et al., 2018).

The MMAT was considered appropriate for this review because AR research in education and physical education often uses varied designs, including experimental, quasi-experimental, mixed-methods, and design-based approaches. Each included empirical study was appraised according to the relevant MMAT category. The quality appraisal was not used to automatically exclude studies, but to inform interpretation of the strength, transferability, and limitations of the evidence.

For theoretical and conceptual papers, quality was assessed narratively based on clarity of argument, relevance to AR-supported learning, theoretical contribution, and connection to children's motor skill learning or physical education pedagogy.

Data Synthesis

The synthesis followed a thematic synthesis approach. Thomas & Harden (2008) describe thematic synthesis as a method for integrating qualitative findings in systematic reviews through line-by-line coding, development of descriptive themes, and generation of analytical themes. This approach was suitable because the purpose of the review was not only to summarize findings but also to develop a theoretical framework explaining AR as a pre-practice pedagogical tool.

The synthesis was conducted in three stages. First, findings and relevant conceptual statements from included studies were coded line by line. Second, similar codes were grouped into descriptive themes related to AR use, learning processes, instructional design, and motor skill outcomes. Third, analytical themes were developed to explain the theoretical role of AR in children's movement learning.

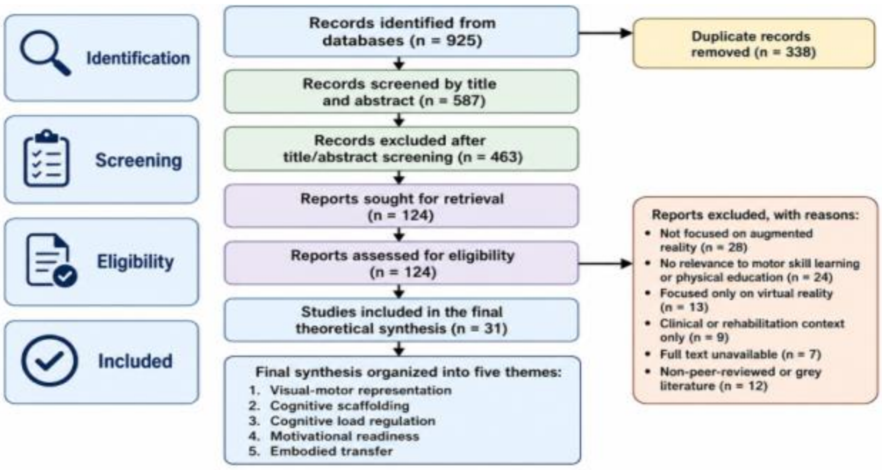
Reflexive thematic analysis principles were also used to support interpretation, particularly in identifying patterns across studies with different designs and theoretical assumptions. Braun & Clarke (2019) emphasize the importance of reflexive engagement when generating themes, especially when the purpose is interpretive rather than purely descriptive.

The final synthesis was organized into five interconnected theoretical themes. First, AR was interpreted as a form of visual-motor representation because it allows learners to observe movement phases, body orientation, and technique sequences before physical practice. Second, AR was understood as cognitive scaffolding, as it can break complex motor skills into smaller and more manageable learning components. Third, AR was positioned as a tool for cognitive load regulation, particularly when it helps reduce instructional ambiguity and presents technical information in a clearer, phased manner. Fourth, AR was identified as a source of motivational readiness, since interactive and visually engaging learning experiences may increase children's attention, confidence, and willingness to participate in movement practice. Fifth, AR was conceptualized as supporting embodied transfer, meaning that it can help learners move from digital visualization toward real physical execution. Together, these themes formed the proposed AR-Based Pre-Practice Pedagogical Continuum, which positions augmented reality as a bridge between seeing, understanding, readiness, and doing in children's motor skill learning.

Study Selection Results

The systematic search identified 925 records from the selected databases. After duplicate records were removed (n = 338), 587 records were screened by title and abstract. At this stage, 463 records were excluded because they were not relevant to augmented reality, physical education, motor skill learning, or pedagogical contexts. A total of 124 reports were sought for retrieval and assessed for eligibility. During full-text assessment, 93 reports were excluded for the following reasons: not focused on augmented reality (n = 28), no relevance to motor skill learning or physical education (n = 24), focused only on virtual reality (n = 13), clinical or rehabilitation context only (n = 9), full text unavailable (n = 7), and non-peer-reviewed or grey literature (n = 12). Finally, 31 sources met the inclusion criteria for the theoretical synthesis, including empirical studies, systematic reviews, meta-analyses, conceptual papers, and methodological sources relevant to the review framework. The study selection process is presented in Figure 2.

Figure 2. PRISMA flowchart Diagram



Note. Final counts are internally consistent across identification, screening, eligibility, and inclusion stages.

Results

Study Characteristics

The final synthesis included 31 sources that met the inclusion criteria for theoretical synthesis. These sources were selected because of their relevance to augmented reality, physical education, motor skill learning, children's learning, swimming instruction, and pre-practice pedagogy. The included sources comprised systematic reviews, meta-analyses, experimental and quasi-experimental studies, conceptual papers, methodological references, and swimming-related studies. Although not all sources focused directly on swimming instruction, each source was included because it addressed at least one dimension relevant to the review framework, namely visual-motor representation, cognitive scaffolding, cognitive load regulation, motivational readiness, embodied transfer, or aquatic competence.

The evidence base came from three complementary domains. First, AR-focused reviews and meta-analyses provided evidence that AR can support learning gains, visualization, engagement, motivation, and interactive learning, while also requiring careful instructional design to avoid cognitive overload and usability problems (Akçayır & Akçayır, 2017; Chang et al., 2022; Garzón et al., 2019; Garzón & Acevedo, 2019; Radu, 2014). Second, physical education and motor competence studies established the developmental importance of children's movement learning and supported the relevance of structured pre-practice preparation in physical education (Barnett et al., 2016; Lorås, 2020; Robinson et al., 2015; Stodden et al., 2008). Third, swimming and aquatic competence studies strengthened the argument that swimming instruction requires not only physical execution, but also visual understanding, confidence, safety awareness, perception, and contextual adaptation (Rejman et al., 2020; Sinclair & Roscoe, 2023; Stallman et al., 2017; Sundan et al., 2023; Taylor et al., 2020).

The characteristics of the included studies are summarized in Table 4. The table presents the author and year, study type or context, learning domain, main contribution to the synthesis, and corresponding theme code. This table provides the evidentiary basis for the thematic synthesis and clarifies how the reviewed literature contributed to the proposed AR-Based Pre-Practice Pedagogical Continuum.

Table 5. Characteristics of Included Studies

Author/year	Study type/context	Learning domain	Main contribution to synthesis	Theme code
Akçayır & Akçayır (2017)	Systematic review	AR in education	Identifies AR advantages and challenges, including visualization, motivation, usability, and technical limitations.	AR-P1, AR-P4
Braun & Clarke (2019)	Methodological paper	Reflexive thematic analysis	Supports interpretive theme development in qualitative and sport-related synthesis.	Method
Buchner et al. (2022)	Systematic review	AR, cognitive load, performance	Shows that AR can reduce or increase cognitive load depending on design quality and task complexity.	AR-P3
Chang et al. (2020)	Quasi-experimental physical education study	AR and motor skills	Shows that AR-assisted instruction can support motor skill learning in physical education, especially for more difficult movement tasks.	AR-P1, AR-P5
Chang et al. (2022)	Meta-analysis	AR in education	Reviews 134 quasi-experimental AR studies and supports AR effects across response, knowledge/skill, and performance outcomes.	AR-P1, AR-P4, AR-P5
Cheng & Tsai (2013)	Conceptual review	AR affordances	Explains AR affordances for visualization, interaction, and contextual learning.	AR-P1, AR-P2
Dunleavy et al. (2009)	Empirical/conceptual AR study	AR simulations	Identifies affordances and limitations of participatory AR learning environments.	AR-P2, AR-P3
Dunleavy & Dede (2014)	Theoretical chapter	AR teaching and learning	Positions AR as a pedagogical approach requiring instructional integration, not merely technology use.	AR-P2
Garzón & Acevedo (2019)	Meta-analysis	AR and learning gains	Shows that AR has a positive effect on students' learning gains across educational contexts.	AR-P1, AR-P5
Garzón et al. (2019)	Systematic review/meta-analysis	AR in educational settings	Synthesizes AR effectiveness and identifies learning gains and motivation as frequent benefits.	AR-P1, AR-P4
Han et al. (2022)	Systematic review	Observational learning in physical education	Supports the role of observation and cue-focused learning in motor skill development.	AR-P1
Hong et al. (2018)	Methodological paper	Quality appraisal	Provides MMAT guidance for evaluating diverse empirical designs.	Method
Ibáñez & Delgado-Kloos (2018)	Systematic review	AR-supported learning	Emphasizes visualization, exploration, simulation, and the need for instructional scaffolding.	AR-P2
Liang et al. (2023)	AR and physical education-related study	Motivation and learning behaviour	Shows that AR can support learning behaviour, engagement, and motivation in physical education-related contexts.	AR-P4
Lorås (2020)	Systematic review/meta-analysis	physical education and motor competence	Establishes physical education as important for improving motor competence in children and adolescents.	AR-P5
Mayer (2014)	Theoretical chapter	Multimedia learning	Provides theoretical basis for visual-verbal integration and limited cognitive processing capacity.	AR-P2, AR-P3
Moreno-Guerrero et al. (2020)	Experimental physical education study	AR in physical education classroom	Shows that AR can improve physical education learning, especially for spatially oriented content.	AR-P1, AR-P4
Page et al. (2021)	Methodological guideline	PRISMA 2020	Provides reporting structure for systematic review identification, screening, eligibility, and inclusion.	Method
Prasetya et al. (2024)	Meta-analysis	AR and motivational design	Shows positive effects of AR learning experiences on attention, relevance, confidence, and satisfaction.	AR-P4

Pratama et al. (2022)	Quasi-experimental study	AR and fundamental motor skills	Demonstrates that AR mobile app-based learning can improve fundamental motor skills in school children.	AR-P1, AR-P2, AR-P5
Radu (2014)	Meta-review	AR in education	Identifies positive and negative impacts of AR learning, including visualization benefits and possible distraction.	AR-P1, AR-P3
Rejman et al. (2020)	Empirical aquatic study	Water competence	Examines perceived and actual swimming skills under different conditions, supporting contextualized aquatic competence.	Swimming, AR-P5
Robinson et al. (2015)	Conceptual review	Motor competence and health	Explains the developmental role of motor competence in positive health trajectories.	AR-P5
Sinclair & Roscoe (2023)	Systematic review	Swimming and fundamental movement skills	Shows that swimming can contribute to children's fundamental movement skill development.	Swimming, AR-P5
Stallman et al. (2017)	Review/conceptual paper	Water competence	Expands swimming skill into broader water competence including cognitive, affective, and safety dimensions.	Swimming, AR-P5
Stodden et al. (2008)	Developmental framework	Motor competence	Explains motor skill competence as a foundation for physical activity and movement development.	AR-P5
Sundan et al. (2023)	Modified Delphi study	Swimming competence assessment	Provides validated content structure for assessing swimming competence.	Swimming, AR-P5
Taylor et al. (2020)	Systematic review	Aquatic competencies and drowning prevention	Supports the importance of aquatic competence and water safety in early childhood.	Swimming, AR-P5
Thomas & Harden (2008)	Methodological paper	Thematic synthesis	Provides basis for descriptive and analytical theme development in systematic reviews.	Method

Thematic Synthesis of AR-Supported Pre-Practice Motor Learning

The thematic synthesis identified five interconnected patterns explaining how augmented reality (AR) was represented in relation to children's motor skill learning before physical execution. These patterns were visual-motor representation, cognitive scaffolding, cognitive load regulation, motivational readiness, and embodied transfer. Across the reviewed literature, AR was commonly described as a preparatory learning support that helped learners observe, interpret, and organize movement information before physical practice.

Several studies provided evidence for these patterns. AR-focused reviews and meta-analyses reported that AR supported visualization, engagement, motivation, and learning gains, although its effects depended on usability and instructional design. Physical education studies indicated that AR-assisted instruction could support motor skill learning, particularly when movement tasks were complex. Studies on children's motor learning further suggested that AR-supported media could help learners engage with movement information before practice. Akçayır & Akçayır (2017) showed that AR can improve learning experiences by making educational content more visible, interactive, and engaging, although usability and technical limitations must be considered. More specifically, Chang et al. (2020) demonstrated that AR-assisted instruction in physical education can support motor skill learning and may be more effective than video-assisted instruction, particularly for more complex movement tasks. Similarly, Pratama et al. (2022) reported that an AR mobile app-based learning medium improved fundamental motor skill learning among children aged 9–10 years, indicating that AR has direct relevance for school-aged learners in physical education contexts.

The synthesis also showed that AR-supported motor learning depended strongly on instructional design. AR was reported to support learning when it clarified movement information, but it could increase cognitive load when the interface was complex or poorly structured. These findings indicate that the role of AR in learning varied according to instructional design, task complexity, and learner support. Table 5 summarizes the five synthesized themes, their pedagogical mechanisms, evidence patterns across studies, and relevance to swimming instruction.

Table 6. Thematic Synthesis of AR-Supported Pre-Practice Motor Learning

Theme	Pedagogical mechanism	Evidence pattern across studies	Relevance to swimming instruction
Visual-motor representation	AR makes movement phases, body orientation, and technique sequences more visible before physical practice.	Studies on AR in education and physical education consistently indicate that AR supports visual-spatial understanding, observation, and representation of complex content. In motor learning contexts, this pattern suggests that AR can extend the function of demonstration by making movement information more repeatable, interactive, and easier to inspect.	Children can observe body position, arm action, leg movement, breathing timing, and whole-body coordination before entering the pool.
Cognitive scaffolding	AR organizes complex movement skills into smaller,	Reviewed studies frequently emphasize that AR is more effective when paired with instructional guidance, step-	Front crawl and breaststroke can be introduced progressively

	structured, and sequential learning units.	by-step learning support, and clear task sequencing. This pattern indicates that AR functions best when it helps learners know what to observe and how to interpret movement information.	through body alignment, leg action, arm action, breathing, glide, and coordination phases.
Cognitive load regulation	AR can reduce instructional ambiguity when information is presented clearly, but may increase cognitive load if design is complex.	Evidence across AR research shows mixed cognitive-load effects. AR supports learning when it clarifies information and reduces abstraction, but it can hinder learning when interfaces are overloaded or poorly structured.	Pre-practice AR can reduce confusion before pool-based instruction, especially for breathing coordination and sequencing, but the design must remain simple and age-appropriate.
Motivational readiness	AR increases attention, interest, confidence, and willingness to participate before physical practice.	Studies commonly report that AR can improve learner engagement and motivational dimensions, particularly when the learning experience is interactive, relevant, and visually meaningful.	For beginner swimmers, AR may reduce uncertainty and make the upcoming aquatic task feel more familiar before direct water exposure.
Embodied transfer	AR supports the transition from digital visualization to bodily execution through prepared visual-cognitive representations.	The synthesis suggests that AR is most valuable when it is connected to real practice rather than used as a standalone digital activity. AR prepares learners for action, but transfer requires teacher feedback, physical repetition, and contextual practice.	Children can transfer visual understanding of movement phases into pool-based performance, including body alignment, arm-leg coordination, and breathing rhythm.

Table 6 shows that the five themes were connected sequentially: visual-motor representation, cognitive scaffolding, cognitive load regulation, motivational readiness, and embodied transfer. Based on this thematic structure, Figure 3 presents the theoretical synthesis framework of AR-based pre-practice learning in children's motor skill development.

Figure 3. Theoretical synthesis framework of AR-based pre-practice learning in children's motor skill development

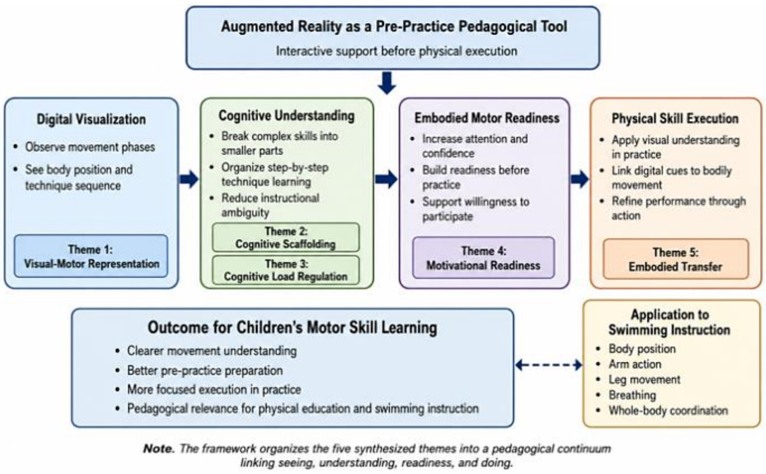


Figure 3 illustrates the proposed theoretical synthesis framework. The framework positions AR as a pre-practice pedagogical tool that supports children's movement learning through four connected stages: digital visualization, cognitive understanding, embodied motor readiness, and physical skill execution. The figure also shows how the five synthesized themes are distributed across these stages and how the framework can be applied to swimming instruction, particularly for body position, arm action, leg movement, breathing, and whole-body coordination.

AR as Visual-Motor Representation

The first theme positions AR as a form of visual-motor representation. Across the reviewed literature, one of the most consistent findings was that AR can make visual information more concrete, spatial, and interactive. This is important in physical education because children often need to understand what a movement looks like before they can perform it. Traditional instruction commonly relies on teacher demonstration, verbal explanation, static images, or video-based learning. These methods remain useful, but they may be limited when movement phases are fast, complex, or difficult to observe from a single angle.

Research on observational learning supports the importance of visual preparation before motor execution. Han et al. (2022) reported that observational learning can support motor skill development in physical education, especially when learners are guided to attend to relevant movement cues. AR extends this function because it allows children to repeatedly observe movement information, focus on particular phases, and connect visual cues with later bodily action.

AR-focused studies also support this theme. Radu (2014) found that AR can improve learning by supporting spatial visualization, physical task integration, and learner engagement, although poorly designed AR can also distract learners. Cheng & Tsai (2013) emphasized that AR affords visualization, interaction, and contextual learning, while Dunleavy & Dede (2014) showed that immersive participatory AR simulations can support learning through situated and interactive experiences, but also require careful design. These studies collectively support the interpretation of AR as a tool for making movement-related information more observable and meaningful before practice.

In swimming instruction, visual-motor representation is especially important. Children must understand body position, arm action, leg movement, breathing rhythm, and whole-body coordination before entering the pool. AR may help learners visualize technical components that are difficult to explain verbally, such as head rotation for breathing in front crawl, the arm recovery phase, or the pull-breath-kick-glide sequence in breaststroke.

AR as Cognitive Scaffolding

The second theme identifies AR as a form of cognitive scaffolding. Across the reviewed literature, AR appeared most pedagogically meaningful when it did not merely display digital content but helped organize learning into smaller and more understandable units. This means that AR-supported learning depends not only on visual attractiveness, but also on instructional structure. Children benefit when AR helps them know what to observe, how to interpret movement information, and how to connect visual cues with later performance.

Ibáñez & Delgado-Kloos (2018) emphasized that AR environments can support learning through visualization, exploration, and simulation, but they also require appropriate learning support and instructional design. Dunleavy & Dede (2014) similarly positioned AR teaching and learning as a pedagogical process that must be meaningfully integrated into instructional design rather than treated as a standalone technological feature. In this sense, AR becomes educationally valuable when it provides structured guidance and helps learners organize complex content.

In physical education, AR-based scaffolding has practical relevance. Chang et al. (2022) showed that AR-assisted instruction can support motor skill learning, especially when learners face difficult movement tasks. Pratama et al. (2022) also reported that AR mobile app-based learning was effective for improving fundamental motor skills among children aged 9–10 years. These findings suggest that AR can support children's movement learning when learning content is presented in a structured, accessible, and phase-based format.

In swimming instruction, AR-based scaffolding may help teachers and coaches divide complex techniques into manageable phases. Front crawl can be scaffolded through body alignment, flutter kick, arm pull, breathing rotation, and whole-stroke coordination. Breaststroke can be introduced through pull, breath, kick, glide, and timing. This phased presentation may reduce confusion and allow children to build a clearer internal structure of the skill before physical practice.

AR as Cognitive Load Regulation

The third theme concerns cognitive load regulation. Motor learning can place high cognitive demands on children because they must listen to instructions, observe demonstrations, control their bodies, respond to feedback, and adapt to the practice environment. In swimming, this cognitive demand is even greater because learners must coordinate technique while adapting to buoyancy, water resistance, and breath control.

The reviewed literature indicates that AR can either support or hinder learning depending on how information is presented. Buchner et al. (2022) reported that AR has mixed effects on cognitive load and performance. In some learning contexts, AR reduces cognitive demand by making content more visible and concrete. In other contexts, AR increases mental effort because of interface complexity, excessive visual information, or unclear instructional sequencing.

This finding is consistent with Radu (2014) meta-review, which identified both positive and negative impacts of AR learning. AR can support spatial understanding and engagement, but it may also distract learners if the design is not aligned with learning goals. Similarly, Garzón & Acevedo (2019) emphasized that AR has positive effects on learning gains, but its impact depends on educational context, implementation quality, and design variables. Together, these findings indicate that AR should not be assumed to improve learning simply because it uses advanced technology. It must be designed to simplify, not complicate, the learning task.

For children's swimming instruction, AR may regulate cognitive load by separating the understanding phase from the execution phase. Before entering the pool, children can use AR to observe movement sequences, identify body positions, and understand when specific actions should occur. This separation between understanding and execution may reduce confusion during pool practice. However, AR for children must use simple navigation, short instructions, clear visual cues, progressive sequencing, and age-appropriate language. If AR contains too many animations, labels, or interactive elements, it may increase cognitive load rather than reduce it.

AR as Motivational Readiness

The fourth theme positions AR as a tool for motivational readiness. Across AR-related literature, engagement and motivation were commonly reported as important benefits, especially when learners experienced AR as interactive, meaningful, and visually attractive. In children's motor skill learning, this motivational function is important because attention, confidence, and willingness to participate influence how learners enter practice.

Akçayır & Akçayır (2017) identified motivation and engagement as recurring advantages of AR in educational settings. Garzón et al. (2019) also found that learning gains and motivation were among the most frequently reported advantages of AR systems in educational settings. Prasetya et al. (2024) further showed that AR learning experiences based on a motivational design model positively influenced motivational dimensions such as attention, relevance, confidence, and satisfaction. These findings support the interpretation of AR as a readiness-building tool before practice.

In swimming instruction, motivational readiness is particularly important because beginners may experience uncertainty, low confidence, or fear before entering the water. AR may help reduce this uncertainty by making the learning task more familiar. When children can observe the movement sequence before practice, they may feel better prepared and more willing to participate. Therefore, AR's motivational function is not simply entertainment; it can become part of a pedagogical strategy for increasing confidence and readiness before physically demanding or unfamiliar movement tasks.

AR as Embodied Transfer from Digital Visualization to Physical Execution

The fifth theme identifies AR as a support for embodied transfer, meaning the transition from digital visualization toward real physical performance. Mayer's cognitive theory of multimedia learning explains that learners build understanding by selecting relevant visual and verbal information, organizing it into coherent mental representations, and integrating it with prior knowledge. In AR-supported motor learning, this process can be interpreted as the development of movement representations that later support bodily execution. In other words, AR may help children move from seeing movement, to understanding movement, and then to applying that understanding in real practice (Mayer, 2014).

The developmental importance of this transfer is supported by motor competence literature. Stodden et al. (2008) proposed that motor skill competence is central to children's physical activity trajectories, while Robinson et al. (2015) argued that motor competence contributes to positive developmental and health-related outcomes. Barnett et al. (2016) further showed that gross motor competence is associated with multiple developmental correlates in children and adolescents. These findings support the argument that pre-practice learning is valuable when it contributes to real movement competence rather than remaining a purely digital experience.

This mechanism is especially relevant for swimming because swimming is both a sport skill and a complex movement activity with educational and safety relevance. Sinclair & Roscoe (2023) reviewed swimming's contribution to fundamental movement skill development among children aged 3–11 years. Stallman et al. (2017) expanded the concept of swimming skill into water competence, emphasizing physical, cognitive, and affective competencies. Rejman et al. (2020) further showed that perceived and real swimming skills may differ under standard and challenging conditions, which supports the need for instruction that strengthens both understanding and performance readiness.

Within this framework, AR helps children move from "seeing" the technique to "understanding" the technique and then to "doing" the technique in practice. In front crawl and breaststroke learning, this may involve transferring visual knowledge of breathing timing, arm movement, leg action, and body alignment into real pool-based performance. The transfer is not automatic, but AR can provide a structured pre-practice foundation that makes embodied learning more prepared, focused, and meaningful.

Research Gap in AR-Based Swimming Instruction

The synthesis also revealed an important gap. Although AR has been increasingly studied in education and physical education, research specifically addressing AR-based swimming instruction for children remains limited. Existing AR studies more commonly focus on general education, STEM learning, physical education activities, fundamental motor skills, sport learning, motivation, or spatial learning. Meanwhile, swimming research has emphasized aquatic competence, fundamental movement skills, water safety, and technique learning, but has rarely integrated AR as a structured pre-practice medium.

Discussion

The findings of this theoretical systematic review suggest that augmented reality (AR) should not be understood merely as an innovative digital medium, but as a structured pedagogical mechanism that can support children's motor skill learning before physical execution. The five themes identified in the synthesis—visual-motor representation, cognitive scaffolding, cognitive load regulation, motivational readiness, and embodied transfer—show that AR has its strongest educational value when positioned as a pre-practice pedagogical tool. This interpretation extends previous AR research, which has shown that AR can improve learning experiences by making content more visible, interactive, and engaging, while also requiring careful attention to usability, cognitive load, accessibility, and instructional design (Akçayır & Akçayır, 2017; Buchner et al., 2022; Radu, 2014). AR reviews and meta-analyses further indicate that AR generally has positive effects on learning gains and learning outcomes, although these effects depend strongly on context, learner characteristics, and design quality (Chang et al., 2022; Garzón et al., 2019; Garzón & Acevedo, 2019).

AR as a Bridge Between Seeing and Doing

The central contribution of this review is the conceptualization of AR as a bridge between seeing, understanding, and doing. In children's physical education, movement learning does not begin when the body starts moving; it begins when learners first observe, interpret, and organize movement information. This interpretation is consistent with observational learning research in physical education, which shows that observing movement models can support motor skill learning when learners are guided to attend to relevant cues (Han et al., 2022). AR expands this pedagogical function by allowing children to revisit movement phases, focus on specific technical components, and connect visual information with later bodily action.

This bridging function is particularly important in swimming instruction. Swimming techniques such as front crawl and breaststroke require learners to coordinate body alignment, arm action, leg movement, breathing, and rhythm in an aquatic environment. For beginners, these components are difficult to understand through verbal explanation alone. AR may therefore help children develop clearer visual-motor representations before entering the pool, reducing the gap between technical explanation and embodied performance. Previous work in physical education has shown that AR can support learning in spatially oriented content, while AR-assisted physical education instruction has also been reported to support motor skill learning more effectively than video-assisted instruction in certain tasks (Chang et al., 2020; Moreno-Guerrero et al., 2020).

From Technological Novelty to Pedagogical Function

One important implication of the synthesis is that AR should not be justified only because it is new, interactive, or visually attractive. Its educational value depends on how well it supports learning processes. This distinction is essential for high-quality AR-based pedagogy. AR becomes pedagogically meaningful when it helps learners identify key movement cues, understand movement sequences, prepare for practice, and connect digital representations with embodied performance. However, AR may become distracting if it adds unnecessary visual complexity or if learners are required to manage too many interface elements during learning.

This issue aligns closely with cognitive load evidence. Buchner et al. (2022) showed that AR can produce different effects on cognitive load and performance: in some cases, AR reduces cognitive demand by making learning content more concrete, while in other cases it increases mental effort because of interface complexity or poorly designed information. Radu (2014) similarly emphasized that AR can support learning through visualization and situated interaction, but can also create distraction or overload when design quality is weak. Therefore, the theoretical contribution of AR in children's motor learning depends not on the technology itself, but on the quality of instructional design. For AR to function effectively as a pre-practice tool, it must simplify movement information, organize it progressively, and avoid overwhelming children with excessive visual or verbal information.

AR and Cognitive Scaffolding in Motor Skill Learning

The findings also indicate that AR can function as a form of cognitive scaffolding. In children's motor learning, scaffolding is essential because complex skills cannot be mastered all at once. Learners need support to break movement into smaller, understandable components. In swimming, for example, front crawl may be scaffolded through body position, flutter kick, arm pull, breathing rotation, and whole-stroke coordination. Breaststroke may be scaffolded through pull, breath, kick, glide, and rhythm. AR can help organize these components visually and sequentially before practice.

This interpretation is consistent with broader AR research in education. Ibáñez & Delgado-Kloos (2018) emphasized that AR environments can support exploration, simulation, and visualization, but require instructional guidance and learning support to become educationally meaningful. Cheng & Tsai (2013) similarly argued that AR's affordances are strongest when visualization, interaction, and contextual learning are aligned with instructional goals. Dunleavy & Dede (2014) further positioned AR teaching and learning as a pedagogical process that requires deliberate instructional integration rather than simply adding technology to existing instruction. In physical education, this means that AR should not simply show a digital movement model. It should guide children toward what to observe, how to interpret the movement, and how the observed information relates to later physical execution.

Motivational Readiness and Emotional Preparation

Another important finding is that AR may support motivational readiness. In children's physical education, motivation is not an additional factor; it directly shapes attention, persistence, confidence, and willingness to participate. AR may increase children's interest because it creates interactive and visually meaningful learning experiences. Akçayır & Akçayır (2017) identified motivation and engagement as recurring benefits of AR in educational settings. Garzón et al. (2019) similarly reported learning gains and motivation as frequent advantages of AR systems, while Prasetya et al. (2024) found that AR learning experiences based on a motivational design model positively influenced attention, relevance, confidence, and satisfaction.

This is particularly relevant for swimming instruction because beginner swimmers often face uncertainty, fear, or low confidence before entering the water. Although AR cannot replace safe pool exposure, instructor supervision, or teacher support, it can make the upcoming task more familiar. When children can see and understand the movement sequence before practice, the aquatic environment may become less intimidating. In this way, AR may contribute to emotional readiness by reducing uncertainty and supporting confidence before physical execution. This motivational function should not be interpreted as entertainment alone; rather, it can be understood as part of a broader readiness-building process that helps children approach complex motor tasks with clearer expectations and stronger participation intent.

Swimming as a Visual-Cognitive-Motor Skill

The discussion also reframes swimming as a visual-cognitive-motor skill, not merely a physical technique. Children must see the movement, understand its structure, and then embody it in the water. This framing is important because swimming requires coordination under environmental constraints that differ from land-based movement. Learners must manage buoyancy, water resistance, body alignment, breathing rhythm, confidence, and safety awareness. Therefore, pre-practice learning has a stronger role in swimming than in many simpler motor tasks.

In swimming instruction, the implementation of AR should therefore be understood within the broader logic of aquatic motor learning. Children do not only learn stroke mechanics; they also learn how to regulate body orientation, breathing, balance, propulsion, confidence, and safety awareness in an unfamiliar environment. This makes swimming instruction different from many land-based motor tasks because the learner must coordinate technical movement while adapting to buoyancy, drag, immersion, and breath control. From this perspective, AR can support the pre-practice stage by making aquatic movement sequences more visible and cognitively organized before children encounter the additional perceptual and emotional demands of the pool environment.

This interpretation is supported by literature on motor competence and aquatic competence. Stodden et al. (2008) conceptualized motor competence as central to children's developmental physical activity trajectories, while Robinson et al. (2015) emphasized its role in positive developmental and health-related outcomes. Barnett et al. (2016) further showed that gross motor competence is associated with multiple developmental correlates in children and adolescents. Within swimming-specific literature, Sinclair & Roscoe (2023) emphasized that swimming may contribute to children's fundamental movement skill development, while Stallman et al. (2017) argued that water competence is broader than swimming skill and includes physical, cognitive, affective, and safety-related dimensions.

Within this broader developmental context, AR-based pre-practice learning may be valuable because it helps children organize technical understanding before direct water-based practice. This does not mean that AR directly produces swimming competence. Rather, AR may provide the visual and cognitive foundation that makes later pool-based instruction more focused and meaningful. For example, AR may prepare children to recognize breathing timing, arm-leg coordination, body alignment, or glide phases before they experience these components in water. The transfer from digital visualization to swimming performance still requires embodied practice, instructor feedback, progressive correction, and repeated exposure.

Theoretical Contribution: The AR-Based Pre-Practice Pedagogical Continuum

The main theoretical contribution of this review is the proposed AR-Based Pre-Practice Pedagogical Continuum. This continuum explains how AR can support learning through four connected stages: digital visualization, cognitive understanding, embodied motor readiness, and physical skill execution. The continuum shifts the discussion of AR away from a simple question—"Does AR improve learning?"—toward a more theoretically useful question: how does AR prepare children for movement learning before practice begins?

This theoretical contribution is grounded in the idea that AR should not replace physical practice, teacher feedback, or embodied movement experience. Instead, AR prepares children for practice by strengthening the visual and cognitive foundations of movement execution. In this sense, embodied transfer is not automatic; it depends on how digital visualization is connected to teacher guidance, progressive practice, feedback, and repeated movement experience.

This contribution follows the logic of theoretical systematic reviews, where the purpose is not only to summarize evidence but to develop an interpretive framework from the literature. In the present review, the continuum offers a framework for understanding AR as a pedagogical bridge between digital representation and embodied performance. This is consistent with AR research showing that learning effects vary according to outcomes and design features, including response, knowledge and skill, and performance outcomes (Chang et al., 2020). It is also consistent with water competence scholarship, which suggests that effective aquatic learning involves more than stroke execution; it also involves perception, judgment, confidence, and adaptation to context (Rejman et al., 2020; Stallman et al., 2017; Sundan et al., 2023).

Implications for Physical Education and Swimming Instruction

The findings have several implications for physical education teachers, swimming coaches, and curriculum developers. First, AR should be used as a complement to physical practice, not as a replacement for teacher demonstration, direct feedback, safe supervision, or real movement experience. Second, AR-based materials should be designed around clear movement phases, simple cues, and age-appropriate language. Third, in swimming instruction, AR may be most useful before pool practice, especially when introducing breathing coordination, arm-leg sequencing, body alignment, glide, and rhythm.

For school and extracurricular swimming programs, AR may help teachers standardize explanations and provide children with repeated exposure to movement sequences before practice. This is especially useful in contexts where pool time is limited, class sizes are large, or children have different levels of readiness. AR-supported pre-practice activities could also be used before pool sessions to introduce technical vocabulary and movement phases, thereby allowing pool time to be used more efficiently for feedback, correction, and embodied practice. However, AR implementation requires teacher preparation. Teachers and coaches must understand not only how to operate the technology, but also how to integrate it into a coherent instructional sequence.

The findings also imply that swimming instruction should be understood through a broader water competence lens. AR may help children visualize swimming techniques, but teachers and coaches should connect these visualizations with confidence, safety awareness, and contextual understanding. This is important because water competence involves more than technical stroke mechanics; it includes the ability to adapt movement and judgment to changing aquatic conditions (Rejman et al., 2020; Stallman et al., 2017).

Limitations and Future Research

This review has several limitations. First, AR research in physical education and swimming instruction remains uneven, with more evidence available from general education, STEM learning, and broader PE contexts than from aquatic skill learning specifically. Second, because this review is theoretical rather than meta-analytic, it does not estimate pooled effect sizes. Third, the proposed continuum is an interpretive framework that requires further empirical testing. Fourth, while 31 studies were included in the synthesis, studies directly examining AR-supported swimming instruction for children were limited, which means that some implications for swimming were developed by integrating evidence from AR education, motor competence, and aquatic competence literature.

Future research should examine AR-based swimming instruction through controlled experimental designs, retention tests, and transfer assessments. Studies should compare AR-supported pre-practice learning with conventional demonstration, video-based instruction, and teacher-led explanation. Future studies should not only test whether AR improves swimming outcomes, but also examine how AR supports movement visualization, cognitive scaffolding, confidence, cognitive load regulation, and transfer to real aquatic performance. Future studies should also investigate which swimming components benefit most from AR, such as breathing timing, arm action, leg movement, body alignment, glide, or whole-body coordination.

Conclusions

This theoretical systematic review synthesized literature on augmented reality, children's motor skill learning, physical education, and swimming instruction to explain how AR may function as a pre-practice pedagogical tool. The synthesis identified five interconnected mechanisms: visual-motor representation, cognitive scaffolding, cognitive load regulation, motivational readiness, and embodied transfer. These mechanisms indicate that AR can support children before physical execution by helping them see, understand, organize, and prepare for movement practice.

The main theoretical contribution of this review is the AR-Based Pre-Practice Pedagogical Continuum, which positions AR as a bridge between digital visualization and embodied motor learning. In swimming instruction, this framework is particularly relevant because children must coordinate body alignment, arm action, leg movement, breathing rhythm, confidence, and safety awareness in an aquatic environment. AR should therefore be understood not as a replacement for pool-based practice, teacher feedback, or embodied experience, but as a preparatory support that may strengthen visual-cognitive readiness before practice.

This review also highlights the limited direct evidence on AR-supported swimming instruction for children. Future empirical studies are needed to test the proposed continuum in real swimming-learning contexts, examine transfer from AR-based pre-practice learning to pool-based performance, and evaluate design factors such as usability, cognitive load, accessibility, and age-appropriate instructional support.

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