

Collaborative Engineering and Augmented Reality for Attention in Children with ADHD: A Systematic Review of Design Requirements

Ingeniería de la colaboración y realidad aumentada en la atención de niños con TDAH: revisión sistemática de requisitos de diseño

Jhoan Sebastian Hurtado Campo¹  Cesar Alberto Collazos Ordoñez¹ 

¹Universidad del Cauca, Faculty of Electronic Engineering and Telecommunications, Popayán, Colombia.

Abstract

Objective: To systematically review the literature on collaborative strategies for improving attention—both with and without augmented reality (AR)—in children with Attention Deficit Hyperactivity Disorder (ADHD), in order to derive design requirements and architectural guidelines for the engineering of collaborative AR systems.

Methodology: A systematic review was conducted in accordance with PRISMA 2020 standards and guidelines for systematic reviews in software engineering. Boolean search strings were applied across Scopus, IEEE Xplore, Google Scholar, and Consensus.app (2015–2026); results were classified into six thematic categories, and a narrative synthesis was performed following SWiM guidelines.

Results: Of the 276 records identified, 58 studies were included. Collaborative strategies improve attention in children with ADHD ($d = -0.33$). Evidence specific to AR is consistent regarding its direction—showing superiority over traditional methods in populations with special needs, alongside validated interventions in reading, cognition, and play—though it is predominantly qualitative and pilot-based in nature; evidence regarding VR, included as the upper limit of the immersive dimension, shows a $d = -1.05$.

Conclusions: The intersection of collaboration engineering, AR, and ADHD represents an open research gap. The derived requirements provide a traceable engineering foundation for the design of multi-user collaborative AR applications aimed at this population.

Keywords: collaboration engineering; augmented reality; ADHD; collaborative learning; serious games; software requirements; software architecture; educational technology.

Resumen

Objetivo: revisar sistemáticamente la literatura sobre estrategias colaborativas para mejorar la atención —con y sin realidad aumentada (RA)— en niños con Trastorno por Déficit de Atención e Hiperactividad (TDAH), con el fin de derivar requisitos de diseño y directrices arquitectónicas para la ingeniería de sistemas colaborativos de RA.

Metodología: revisión sistemática realizada conforme a las normas PRISMA 2020 y a las directrices para revisiones sistemáticas en ingeniería de software. Se aplicaron cadenas de búsqueda booleanas en Scopus, IEEE Xplore, Google Scholar y Consensus.app (2015–2026), clasificando los resultados en seis categorías temáticas y realizando una síntesis narrativa estructurada según las directrices SWiM.

Resultados: de los 276 registros identificados, se incluyeron 58 estudios. Las estrategias colaborativas mejoran la atención en niños con TDAH ($d = -0.33$). La evidencia específica sobre RA es consistente en cuanto a su dirección —superioridad frente a métodos tradicionales en poblaciones con necesidades especiales e intervenciones validadas en lectura, cognición y juego—, aunque de naturaleza predominantemente cualitativa y piloto; la evidencia sobre RV, incluida como límite superior de la dimensión inmersiva, alcanza una $d = -1.05$.

Conclusiones: la intersección entre la ingeniería de la colaboración, la RA y el TDAH constituye una brecha de investigación aún abierta. Los requisitos derivados proporcionan una base de ingeniería trazable para el diseño de aplicaciones colaborativas de RA multiusuario dirigidas a esta población.

Palabras clave: Ingeniería de la colaboración; realidad aumentada; TDAH; aprendizaje colaborativo; juegos serios; requisitos de software; arquitectura de software; tecnología educativa.

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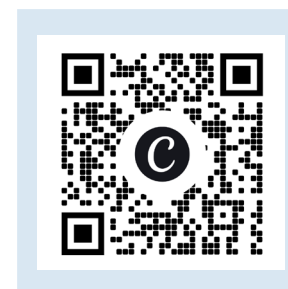
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Correspondence

jhoanhurtado@unicauca.edu.co



Spanish version



Why was the study conducted?

Children with ADHD face attentional difficulties that affect their school performance, and both collaborative strategies and augmented reality have separately shown potential to support them. However, software developers lack design criteria traceable to evidence: the available findings are scattered across clinical, educational and engineering literature, and are not translated into specifications that a development team can implement and verify. This study was conducted to synthesise that fragmented evidence and turn it into concrete design requirements for collaborative augmented reality systems aimed at this population.

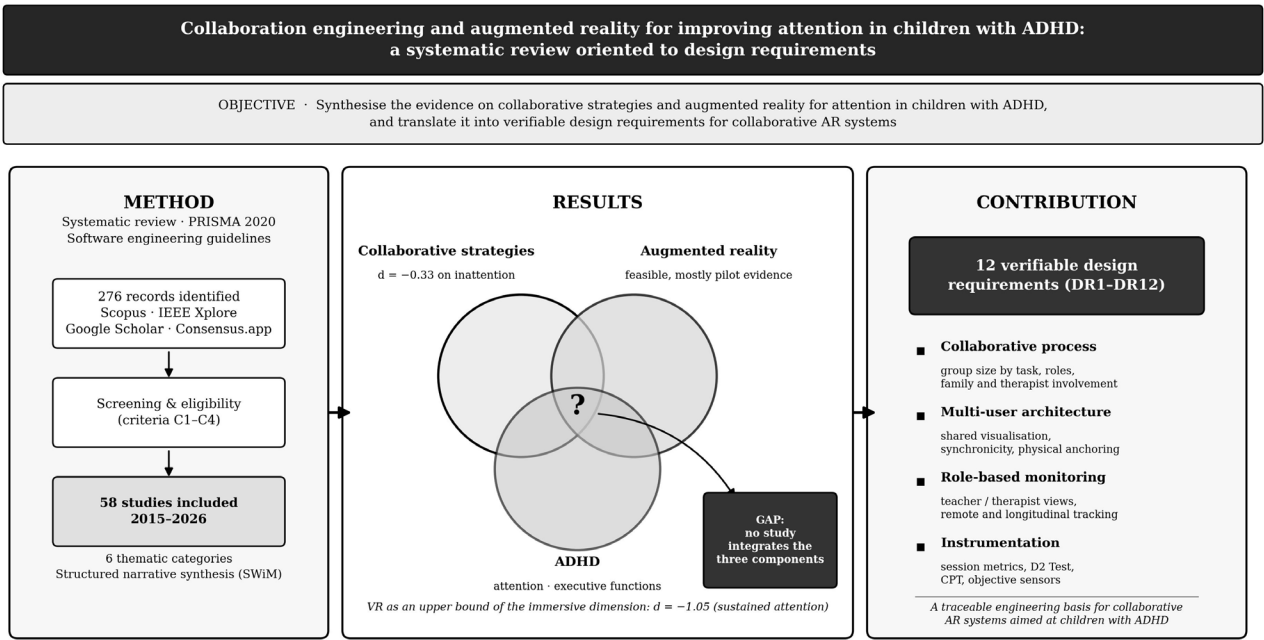
What were the key findings?

Of 276 records identified, 58 studies were included. Collaborative strategies improve attention in children with ADHD with a moderate effect ($d = -0.33$), consistent across school-based and digital-intervention meta-analyses. AR-specific evidence is consistent in direction—with interventions validated in reading, cognitive tasks and play—although predominantly qualitative and pilot in nature; virtual reality evidence, included as an upper bound of the immersive dimension, reaches $d = -1.05$ for sustained attention. No study integrating structured collaboration, augmented reality and ADHD simultaneously was identified in the retrieved corpus.

What do these findings contribute?

The study translates heterogeneous clinical and educational evidence into twelve verifiable design requirements (RD1–RD12), traceable to their sources and organised into collaborative process, multi-user architecture, role-based monitoring and measurement instrumentation. This gives development teams an engineering basis for specifying and validating collaborative augmented reality applications, rather than starting from design intuition. The requirements do not constitute a demonstration of efficacy—that empirical verification remains pending—but a grounded and testable starting point, which also delimits a research agenda at the as-yet unexplored intersection of collaboration, augmented reality and ADHD.

Graphical Abstract



Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental condition characterised by symptoms of inattention, hyperactivity and impulsivity that affect children's academic performance, social interaction and emotional development [\(1, 2\)](#). Current clinical guidelines stress the need for multimodal approaches integrating psychosocial and technological components alongside conventional treatments [\(1\)](#), and the evidence documents impairments across multiple domains: cognitive, motor, social and emotional [\(3\)](#). From an engineering perspective, these characteristics constitute constraints and operating conditions that any interactive system aimed at this population must explicitly incorporate into its design.

In parallel, collaboration engineering has become established as a discipline oriented towards the design and deployment of repeatable, high-value collaborative processes that can be executed by practitioners without the ongoing support of expert facilitators [\(4\)](#). Its basic design unit, the thinkLet, encodes facilitation interventions that produce predictable patterns of collaboration, and its design approach has been validated through multi-method design science studies [\(5\)](#). This discipline provides the conceptual scaffolding to transform empirical findings on collaboration—group size, role assignment, feedback—into process specifications reusable by the software engineers who build collaborative systems.

Augmented reality (AR), in turn, has emerged as an immersive technology capable of enriching educational processes through visual environments that integrate digital content with the physical world [\(6, 7, 8\)](#). In settings involving children with ADHD, AR has been shown to improve concentration and reduce distraction through multisensory experiences [\(9, 10, 11\)](#), and a comparative study between desktop, virtual reality (VR) and AR environments indicates that AR is particularly suitable for school contexts because of its integration with the physical environment and its lower technical burden [\(12\)](#). Nevertheless, a recent systematic review on AR in collaborative learning warns that AR has more frequently been implemented for content delivery than for promoting collaboration, and that the literature lacks validated instruments to measure the collaborative dimension in these environments [\(13\)](#).

Despite growing interest in these three lines of work, an exploration of the literature available in Scopus, IEEE Xplore and Google Scholar did not identify previous systematic reviews that simultaneously and systematically integrate: (1) collaborative strategies as the main intervention mechanism, (2) AR as the supporting technology, and (3) ADHD as the validation population. Existing studies address, at most, two of these components jointly [\(14, 15\)](#), and the most recent reviews on immersive technologies in ADHD confirm that the evidence remains fragmented and methodologically heterogeneous [\(16\)](#).

This article addresses that gap from an engineering standpoint. Unlike reviews focused on clinical effectiveness, the contribution of this work consists in synthesising the available evidence in order to derive from it verifiable design requirements and architectural guidelines for multi-user collaborative AR systems aimed at children with ADHD. The review analyses literature published between 2015 and 2026, identifies patterns of effectiveness, mechanisms and empirical gaps, and translates them into twelve design requirements (DR1–DR12) traceable to their sources. These requirements underpin the development of the collaborative AR application proposed in the

Master's thesis in Computing at Universidad del Cauca within which this review is framed.

Conceptual framework

This review is framed by six constructs that warrant theoretical precision. ADHD is understood, following the European consensus clinical guidelines (1), as a neurodevelopmental disorder of multifactorial origin characterised by persistent patterns of inattention, hyperactivity and impulsivity that interfere with functioning and development; this clinical perspective is adopted here in its functional dimension, that is, as a set of cognitive and behavioural characteristics—deficits in executive functions, working memory and response inhibition (3)—that operate as design constraints for any interactive system aimed at this population.

Collaboration engineering is adopted in the definition of Briggs, de Vreede and Nunamaker (4) as the approach oriented towards the design of recurring, high-value collaborative processes that can be executed in a self-sustaining manner by domain practitioners without the ongoing intervention of expert facilitators. Its design unit, the thinkLet, encodes reproducible facilitation patterns; the collaborative process design framework of Kolfshoten and de Vreede (5) complements this perspective by formalising the activities of decomposition, selection and sequencing of patterns. Under this approach, collaboration is not treated as an emergent feature of interaction, but as a specifiable and verifiable process that can be incorporated into requirements engineering.

Augmented reality is defined, in the canonical sense of Azuma (17), as a system that combines real and virtual elements in a real environment, is interactive in real time and is registered in three dimensions. This definition is situated within the virtuality continuum of Milgram and Kishino (18), which orders environments between the completely real and the completely virtual and makes it possible to formally distinguish AR from virtual reality: whereas AR superimposes digital content onto the physical environment while preserving it as the substrate of interaction, virtual reality replaces that environment with a synthetic one. This distinction is relevant to the present review because anchoring to the physical environment—and not only the degree of immersion—is one of the properties that underpins the school viability of AR and several of the requirements derived in this work.

Attention, the outcome variable of this review, is approached from the attentional networks model of Posner and Petersen (19), which conceives it not as a unitary capacity but as a system anatomically independent of processing systems, organised into differentiated networks of alerting, orienting and executive control; the subsequent update of this framework (20) incorporates evidence on the development of these networks in childhood and their relationship with self-regulation. This distinction is operationally relevant because the instruments used in the reviewed studies do not measure the same construct: continuous performance tests and the D2 Test mainly assess sustained and selective attention, whereas parent and teacher rating scales capture behavioural manifestations of inattention. In this review, “attention” designates the set of these functions insofar as they are the object of measurement in the included studies, with an emphasis on sustained attention during the activity.

Collaboration is adopted in the definition of Roschelle and Teasley (21) as a coordinated, synchronous activity resulting from a continued attempt to construct and maintain a shared conception of a problem, sustained on a joint problem space negotiated among participants.

This definition is more restrictive than that of cooperation —where the task is divided and each participant solves a part independently— and is the one applied in this review to determine whether a study incorporates a collaborative axis: interdependence and joint construction are required, not merely the grouping of participants.

Finally, a design requirement is understood, in accordance with the ISO/IEC/IEEE 29148 standard (22), as a statement that expresses a need and its associated constraints in a verifiable manner, that is, one that can be checked through inspection, analysis, demonstration or test. The requirements derived in this work are classified into three types: collaborative process requirements (conditions on how the activity is structured among participants), functional requirements (capabilities the system must provide) and non-functional requirements (quality properties and constraints under which it must operate).

Methodology

Type of study

This study is a systematic review of the scientific literature carried out within the framework of a Master's research project (23). The PRISMA 2020 guidelines were followed (24), complemented by the guidelines for systematic reviews in software engineering (25), which guide the planning, conduct and reporting of reviews in this disciplinary field.

The high methodological heterogeneity of the included studies makes a quantitative meta-analysis technically unfeasible for three concurrent reasons: (a) the designs range from pilot experiments with $n < 10$ to meta-analyses with $n > 1000$, with no homogeneous effect unit; (b) the attention measurement instruments are mutually incommensurable (parent rating scales, CPT, D2 Test, EEG, eye tracking); and (c) the interventions differ substantially in the type of collaborative strategy, the technology employed and the duration of the programme, which prevents the definition of a common comparator. For these reasons, and following the SWiM (Synthesis Without Meta-analysis) guidelines (26), a structured narrative synthesis was adopted: studies were grouped by thematic category, findings were synthesised within each group, and patterns were compared across groups to identify convergences, contradictions and knowledge gaps.

Research questions

The following questions, formulated from the engineering perspective of the target system, guided the review: (Q1) Which behavioural and cognitive characteristics of children with ADHD condition the requirements of an interactive system oriented towards attention? (Q2) Which collaborative strategies and patterns have demonstrated effectiveness in improving attention, and which process parameters (group size, roles, feedback) do they report? (Q3) How does AR contribute to strengthening collaborative strategies, and which architectures, platforms and measurement instrumentation do the reported systems employ? (Q4) Which verifiable design requirements can be derived from the evidence for collaborative AR systems aimed at this population?

Information sources and search strategy

The search was conducted in Scopus, IEEE Xplore, Google Scholar and Consensus.app, for articles published between January 2015 and June 2026. Combinations of the keywords “attention deficit hyperactivity disorder”, “ADHD”, “collaborative learning”, “collaborative strategies”, “Augmented Reality”, “attention improvement”, “technology”, “children” and “behavioral interventions” were used. The search strings with Boolean operators were: (1) “ADHD children” AND “characterization” AND (“attention deficit” OR “hyperactivity disorder”); (2) “collaborative strategies” AND “attention improvement” AND “ADHD children”; (3) “Augmented Reality” AND “collaboration” AND “attention”; (4) “ADHD AND Augmented Reality AND collaborative learning”; (5) “serious games” AND “ADHD” AND “attention” AND (2024 OR 2025 OR 2026); and (6) “immersive technology” AND “collaborative learning” AND “special needs”.

The searches were run between March and April 2026. In Scopus and IEEE Xplore the strings were applied to the title, abstract and keyword fields; in Google Scholar they were restricted to the article title; and in Consensus.app they were run broken down into semantic queries. This difference reflects the role assigned to each source: Scopus and IEEE Xplore operated as primary bibliographic databases—the former for its indexed multidisciplinary coverage and the latter for its specialisation in engineering and interactive systems—whereas Google Scholar and Consensus.app were used as complementary retrieval sources, aimed at identifying Ibero-American literature, open-access literature, or literature not retrieved through exact term matching. Accordingly, every record originating from these last two sources was validated by verifying its DOI and metadata in the primary databases before being retained, so that no study was included solely on the basis of a complementary source.

The 2015–2026 time window was established under two explicit criteria: (i) the topic modelling analysis of 3718 educational AR articles conducted by Ozyurt and Ozyurt (27) documents that publication volume grew slowly until 2015 and accelerated markedly from that year onwards, coinciding with the widespread adoption of mobile devices with AR capabilities and with the emergence of serious game applications, including those aimed at populations with neurodevelopmental conditions, so that 2015 constitutes a cut-off point documented in the bibliometric literature of the field; and (ii) a coverage of approximately one decade makes it possible to observe the evolution of the field and its development trends, while maintaining the technological currency of the systems analysed.

Selection criteria

Studies published between January 2015 and June 2026, in English or Spanish, were included, corresponding to peer-reviewed journal articles, book chapters with an editorial process, or conference papers with a review committee; that applied collaborative strategies with or without technology; that used AR or VR as a supporting tool (where applicable); that had as their observation group children with ADHD—the main population of interest of this review—or, on a complementary basis, other neurodevelopmental conditions involving attentional difficulties whose evidence informs the design of interventions for ADHD; and that presented empirical results or a verifiable systematic synthesis on attention or related cognition. The inclusion of VR

studies responds to a deliberate methodological decision: since controlled primary studies of AR with ADHD populations are still scarce, VR evidence was incorporated as adjacent evidence of the immersive dimension—useful for bounding design parameters and reference effect magnitudes—while keeping AR as the target technology of the review and explicitly distinguishing in the synthesis the provenance of each finding by platform. Studies were excluded if they lacked explicit results on attention, lacked a reproducible methodological description, did not include collaboration as a relevant component of the intervention, focused exclusively on pharmacological treatment, or corresponded to grey literature or duplicates (retaining the most recent version or the one with the broader methodological scope). The application of these criteria to the total number of records identified is quantified in the flow diagram in Figure 1 and detailed in the following section, indicating how many records were excluded at each stage and under which specific criterion.

Selection process and quality appraisal

The process was carried out in three stages: identification through keyword searching, screening by title and abstract, and full-text reading of eligible articles. Given the heterogeneous design of the included studies, each study was appraised narratively according to four minimum quality criteria, inspired by the core domains of the CASP tool (28) and consistent with quality appraisal practice in software engineering reviews (25): (C1) clear description of the methodological design; (C2) explicit characterisation of the population or sample; (C3) detailed description of the intervention or tool; and (C4) reporting of quantifiable results or a reproducible analytical synthesis. Studies that did not meet at least three of the four criteria were discarded during the eligibility stage.

The four criteria were derived from the core domains common to the CASP instruments—design validity, clarity in the characterisation of the population, description of the intervention and reporting of results—selected because they are the ones applicable in a uniform manner to a corpus combining controlled trials, quasi-experimental studies, systematic reviews and technological development work. This threshold was set in this way so as not to systematically exclude technological development studies, which tend to describe the population in less detail but provide architectural information essential to the derivation of requirements. The appraisal was applied during full-text reading: whenever there was any doubt about the fulfilment of a criterion, the study was read in full and contrasted against the four criteria before a decision was made, recording in the extraction form the decision and, in the case of exclusion, the specific criterion that motivated it. The review was carried out by the first author and verified by the second.

Figure 1 illustrates the selection process in accordance with PRISMA 2020. A total of 276 records were identified across four sources: IEEE Xplore ($n = 80$), Scopus ($n = 87$), Consensus.app ($n = 49$) and Google Scholar ($n = 60$). After removing duplicates ($n = 34$), the corpus was reduced to 242 records. Screening by title and abstract removed 157 records, leaving 85 for full-text assessment, of which 27 were excluded for failing to meet the eligibility criteria, resulting in 58 studies included in the synthesis. The arithmetic verification of the flow is: $276 - 34 = 242$; $242 - 157 = 85$; $85 - 27 = 58$. In summary, of the 276 records initially identified, 34 were excluded as duplicates across sources, 157 during screening by title and abstract (89 for having no thematic relation to the object of study, 28 for ineligible language and 40 for not being peer-reviewed) and 27 during full-text

assessment (9 for not reporting results on attention, 8 for lacking a reproducible methodological description, 6 for not including collaboration as a relevant component and 4 for addressing pharmacological treatment exclusively), which delimits the final scope of the corpus at 58 studies.

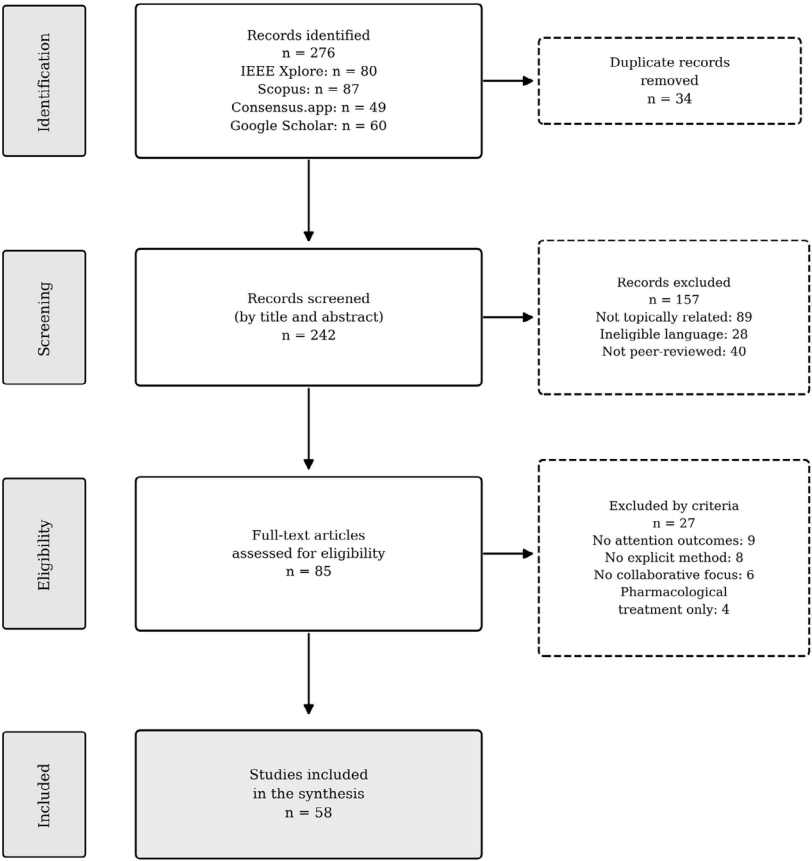


Figure 1. PRISMA 2020 flow diagram of the study selection process. Source: prepared by the authors.

Data extraction and synthesis

Data from each study were extracted by means of an extraction form designed ad hoc by the authors for this review, whose structure follows the data extraction guidelines established by PRISMA 2020 (24) and the recommendations for systematic reviews in software engineering of Kitchenham et al. (25), which prescribe recording in a uniform manner the methodological and contextual attributes needed to answer the research questions. The form recorded the following fields: authors and year, type of design, application context, collaborative strategy employed (where applicable), technology used, population and sample size, attention measurement instruments, main results and relevant conclusions.

Articles were categorised into six thematic groups: (1) characterisation of children with ADHD, (2) collaborative strategies applied to ADHD, (3) general collaborative strategies, (4) digital tools for



improving attention, (5) AR and VR tools, and (6) combined studies. In addition, and as a distinctive contribution of this review, each finding with design implications was coded as a candidate requirement and consolidated through traceability to its sources, following the logic of deriving requirements from evidence proper to software engineering (25) and collaboration engineering (5). For the purposes of this categorisation, digital tools for improving attention are understood as the set of computer-mediated interventions—digital therapeutics, serious games and cognitive training programmes—specifically designed to exercise attentional and executive functions through structured tasks with feedback, and evaluated as an intervention in their own right rather than as support for another activity (53, 31); this category is distinguished from category 5 in that the latter requires mediation by augmented or virtual reality technologies in accordance with the definition adopted in the conceptual framework (17, 18).

Results

The selection process resulted in the inclusion of 58 articles published between 2015 and 2026, with particular density in the 2021–2026 period, in which research on immersive technologies for ADHD has shown greater dynamism and methodological rigour. Appraisal against criteria C1–C4 showed that most studies in categories 1, 2 and 4–6 display acceptable methodological traceability (three to four criteria met); the highest-quality studies were the meta-analyses and systematic reviews, which provide verifiable quantitative effect estimates, as against case studies and pilots, which contribute exploratory evidence relevant to design. Table 1 summarises the characteristics of the corpus by thematic category; the individual characterisation of the 58 studies is provided as supplementary material in spreadsheet format, in accordance with the journal’s data availability policies.

Table 1. Summary of the corpus by thematic category (n = 58). SR: systematic review; MA: meta-analysis; RCT: randomised controlled trial; SLR: systematic literature review. Source: prepared by the authors.

Thematic category	n	Predominant designs	Technologies	Key finding for design
1. Characterisation of ADHD (1 , 2 , 3 , 9 , 29 , 30 , 31)	7	Clinical guidelines, umbrella reviews, SR/MA, interventions	Digital (partial)	Cognitive, motor and social domains as target variables; greater behavioural engagement in collaborative structures than in direct instruction.
2. Collaborative strategies applied to ADHD (32 , 33 , 34 , 35 , 36 , 37)	6	RCTs, SR/MA (26 RCTs), longitudinal follow-ups	Mostly non-technological	Effects on inattention ($d = -0.33$), academic performance ($d = 0.37$) and social skills ($d = 0.28$); increasing family involvement improves the efficacy of the intervention and the transfer of skills.



Thematic category	n	Predominant designs	Technologies	Key finding for design
3. General collaborative strategies (38 , 39 , 40 , 41 , 42 , 43 , 44 , 45)	8	Experiments, SLRs, observational and quantitative studies	Mixed (digital, robots)	Group size moderates the relationship between peer support and engagement, with no single optimal value; elements that structure and support collaborative experiences (shared goals, roles, feedback, adult scaffolding, peer reflection); collaborative behavioural profiles; positive interdependencies and groups of four participants in collaborative tools.
4. Digital tools for attention (46 , 47 , 48 , 49 , 50 , 51 , 52 , 53 , 54 , 55)	10	MA (25 RCTs, n = 1780), SRs, pilots, RCTs, interventions	Serious games, digital therapeutics, VR	Overall effect SMD = -0.33, greater in programmes ≥ 8 weeks; immediate feedback and difficulty adaptation are relevant features; neurobiological evidence (EEG) of attentional improvement.
5. Augmented and virtual reality (6 , 7 , 8 , 10 , 11 , 12 , 16 , 56 , 57 , 58 , 59 , 60 , 61 , 62 , 63 , 64 , 65 , 66 , 68)	19	Platform comparisons, MAs, SRs, interventions, RCT protocols	AR, VR, eye tracking, NIRS	AR is situated at an intermediate point of the desktop–VR continuum, suitable for school settings; immersive VR reaches d = -1.05 on sustained attention; tangible AR is feasible; superiority of AR in special needs populations; fragmented evidence for social behaviours in ADHD.



Thematic category	n	Predominant designs	Technologies	Key finding for design
6. Combined studies (13 , 14 , 15 , 67 , 69 , 70 , 71 , 72)	8	Three-arm RCTs, SRs, system designs and evaluations	VR, AR, mixed reality	No study explicitly integrating the three components was identified in the corpus; ITCL framework; multi-user collaborative AR patterns; asymmetric monitoring for the teacher; collaborative AR lacks process structure and instruments for measuring collaboration.

ADHD as a source of design constraints

The first category of the corpus makes it possible to answer Q1. European clinical guidelines stress the need for multimodal approaches with psychosocial components ([1](#)), and meta-analytic evidence quantifies the impairment in quality of life, executive functions and social relationships associated with ADHD ([2](#), [3](#)). Diagnostic tools display gender biases and overlap with comorbidities that must be taken into account when selecting assessment instruments for any system aimed at this population ([29](#)). Two findings have direct engineering implications: the behavioural engagement of children with ADHD is greater in collaborative structures than in direct instruction ([9](#)), which positions collaboration as a design mechanism rather than an accessory; and executive function training shows significant improvements even in preschoolers ([30](#), [31](#)), which defines response inhibition and working memory as cognitive domains that the system must stimulate ([55](#)).

Collaboration engineering: process parameters with empirical support

Collaboration engineering provides the framework for converting the evidence from categories 2 and 3 into repeatable process specifications ([4](#), [5](#)). In ADHD populations, collaboration among families, teachers and health professionals produces significant and sustained benefits in symptoms and quality of life ([32](#), [33](#), [36](#), [37](#)). The most comprehensive meta-analysis available, integrating 26 school-based randomised controlled trials with child populations with ADHD, quantifies the effects on inattention ($d = -0.33$), academic performance ($d = 0.37$) and social skills ($d = 0.28$) ([34](#)). The evidence indicates that increasing family involvement in the intervention improves its efficacy and the transfer of skills to the child’s natural environment ([35](#)), which in software engineering process terms implies incorporating parents and therapists as active stakeholders in the design and validation cycle.

Studies of collaboration in general contexts provide the process parameters that collaboration engineering requires in order to instantiate patterns. Group size operates as a moderating variable of the relationship between peer support and engagement, without the evidence establishing a single optimal value: smaller groups favour individual participation and mutual support, whereas larger configurations may be appropriate for other types of task, so that sizing must be decided



according to the nature of the activity (44); Burns et al. highlight various elements that structure and support collaborative experiences, among them the establishment of shared goals and the assignment of roles, knowledge exchange through feedback, adult-provided scaffolding, and processes of perspective taking and reflection among peers (45); defined roles and peer review produce greater understanding than individual work in technological environments (39, 40, 41); and the collaborative tool CCCuento, structured on positive interdependencies and a sequence of individual activities alternating with periods of review and discussion in groups of four participants, incorporates mechanisms of equitable participation and monitoring that are transferable to AR systems, with synchronicity being a possible complement rather than an essential condition of the design (38). The multimodal profiles of collaborative behaviour identified through learning analytics make it possible to anticipate group dynamics and underpin alerting and re-engagement functions (42), while hybrid environments combining physical and virtual activity enhance reflective thinking (43). These parameters constitute the input for requirements DR1–DR3 and DR11 in Table 2.

Augmented reality: platforms, architectures and instrumentation

Categories 4 and 5 answer Q3 in its technological dimension. It is worth distinguishing here, explicitly, the evidence according to platform. AR-specific evidence is consistent in direction and growing in volume: the meta-analysis by Baragash et al. —the only one in the corpus focused exclusively on AR— reports effects superior to those of traditional methods for skill acquisition in people with special needs —a population that includes, but is not limited to, ADHD— (57), a finding corroborated in populations with autism spectrum disorder (66); multiple interventions validate AR for ADHD in reading (60, 61), cognitive (10, 11) and serious-game contexts with motion capture, where improvements are reported in frustration tolerance, attention and execution times (62); and the empirical comparison between desktop, VR and AR environments shows a trade-off between measurement precision —highest in desktop environments— and immersion —highest in VR— placing AR at an intermediate point of the virtuality continuum (12); this intermediate position, combining anchoring to the physical environment with a moderate degree of immersion, supports its relevance for school contexts in which the need for reliable data coexists with the need to sustain student engagement.

This AR evidence is, however, predominantly qualitative, pilot or quasi-experimental, with small samples. The detail of these native AR interventions makes it possible to specify their contribution: the augmented literacy programme evaluated by Tosto et al. (60) applied AR to printed reading material with children with ADHD, reporting effects on motivation and engagement rather than on standardised academic outcomes; the AHA project (61) implemented an evidence-based AR intervention for reading and spelling in the same population, confirming its feasibility in real school settings; the tangible AR proposal of Wang and Hsu (10) employed augmented physical blocks, demonstrating that anchoring to manipulable objects is technically feasible with this population; and the AR serious game with motion capture of Avila-Pesantez et al. (62) reported improvements in sustained attention, execution times and frustration tolerance during the task. In the Latin American context, the intervention of Lancheros-Cuesta and Mogollón (11) documents attentional improvements and high teacher acceptability in Colombian educational settings. Taken together, this body of work shows that AR has its own evidence of feasibility and effect in ADHD, albeit with designs of lower statistical power than those available for VR.

The quantitative evidence of greatest magnitude comes from adjacent platforms and should be read as an upper bound of the immersive dimension, not as a direct estimate of the effect of AR. The meta-analysis with the largest available sample on digital interventions in children and adolescents with ADHD (25 RCTs, $n = 1780$) establishes $SMD = -0.33$ as the overall effect on symptomatology, with greater magnitude in programmes of eight weeks or more (53), a parameter corroborated by the most recent review on VR (65). The effectiveness ceiling of the immersive dimension is set by the VR meta-analysis with $d = -1.05$ on sustained attention (64). Immediate feedback and difficulty adaptation constitute relevant features of serious games for children with ADHD, as they contribute to sustaining attention, motivation and the personalisation of the intervention (31, 54), and neurobiological evidence from EEG documents improvements in markers of sustained attention (49). The fact that AR shares with VR the mechanisms of immersion, novelty and multisensory stimulation (51, 52) makes the transfer of these magnitudes plausible—but does not guarantee it—which reinforces the need for primary AR studies to verify them.

From an architectural and instrumental standpoint, the corpus provides concrete models. The REEFocus system proposes a VR/AR game architecture with remote progress monitoring for the non-pharmacological treatment of ADHD (67). The asymmetric mixed reality system of Pan et al. provides teachers with real-time student data to support pedagogical decision-making, defining a monitoring pattern with role-differentiated views (70). In the specific field of AR for ADHD, the AHA project integrates AR objects with a web monitoring application, generating a shared service that allows parents, teachers and professionals to track the child's behaviour during activities (61). The review of multi-user collaborative AR applications in primary and secondary education consolidates design patterns of shared visualisation, roles and synchronicity (14). In terms of measurement instrumentation, the corpus documents the use of the D2 Test with a reduction in commission errors in serious games (46), clinical scales validated in digital therapy RCTs (48), eye tracking as an objective measure of attentional fixation (56), EEG markers (49) and neurofeedback protocols with NIRS in a virtual classroom (63). These elements underpin requirements DR5–DR9 in Table 2.

The intersection of collaboration, AR and ADHD

Category 6 documents the state of the sought-after intersection. The three-arm randomised controlled trial of Wong et al. ($n = 90$) combines VR with social skills training for ADHD, showing improvements in social interaction and emotional regulation, but without AR as a mediator of collaboration (15). The ITCL framework (immersive technology-supported collaborative learning) articulates the dimensions of pedagogical context, human agents and technological mediation, offering the most robust theoretical basis for designing collaborative AR (72). The study with AR picture books by Yang et al. (68), conducted with 40 children aged 9 to 11, provides empirical support for AR-based multisensory interaction design in special education and shows that cognitive load exerts a negative moderating effect on the pathway linking attention with emotional regulation, with divergent patterns between children with and without ADHD; reviews of immersive environments for special education identify the implementation conditions that maximise benefits (69, 71). The systematic review of AR in collaborative learning, published in 2025, converges with this diagnosis from the general educational side: collaboration is mostly implemented in basic configurations without process structure, and there are no consolidated instruments to assess it

(13). The most recent narrative review on AR and VR interventions for social behaviours in ADHD confirms that the evidence remains fragmented (16). Taken together, within the corpus retrieved through the described search strategy, no study was identified that explicitly and simultaneously integrates structured collaborative strategies, AR as a mediating technology and ADHD as the validation population. From this observation follows a necessary qualification for the interpretation of the results: the available evidence on AR comes from individual applications or from populations broader than ADHD, and therefore does not constitute a demonstration of the efficacy of collaborative AR systems specifically designed for this population. It is precisely that absence which defines the gap and which motivates formulating the findings as verifiable design requirements rather than as conclusions about effectiveness.

Design requirements derived from the evidence

In answer to Q4, Table 2 consolidates twelve design requirements (DR1–DR12) derived from the preceding synthesis. Each requirement is traceable to the sources that support it, distinguishes its nature (collaborative process, functional system requirement or non-functional requirement) and is formulated in a verifiable manner, so that it can be incorporated directly into the requirements specification of a collaborative AR system for children with ADHD. Regarding the provenance of the evidence by platform, it should be noted that the requirements derived partly from VR studies (DR4, programme duration; DR9, measurement instrumentation; DR12, frustration tolerance) correspond to aspects independent of the rendering modality —temporal parameters, sensors and game mechanics— so that their transfer to AR is defensible; by contrast, platform-specific requirements (DR8, anchoring to the physical environment) rest on direct comparative evidence between AR and VR (12) and on native AR interventions (10). This table constitutes the central engineering contribution of the review: it converts heterogeneous clinical and educational findings into actionable inputs for software design and validation.

Table 2. Design requirements (DR1–DR12) derived from the evidence, with traceability to sources. Source: prepared by the authors

ID	Design requirement	Nature	Supporting evidence
DR1	The system must allow the group size to be configured according to the task, favouring small groups when the aim is to maximise individual participation and peer support.	Collaborative process	Group size moderates the relationship between peer support and engagement (44); the CCCuento tool operates with groups of four participants and positive interdependencies in a school context (38).

ID	Design requirement	Nature	Supporting evidence
DR2	The system must support explicit role assignment and mechanisms for equitable participation within the activity.	Process / Functional	Elements that structure and support collaborative experiences: shared goals, roles, feedback, scaffolding and reflection (45); roles and peer review (39); equitable participation and monitoring in collaborative tools (38).
DR3	The system must provide adaptive real-time feedback adjusted to the child's performance.	Functional	Immediate feedback and difficulty adaptation contribute to sustaining attention, motivation and the personalisation of the intervention (54).
DR4	The system must support intervention programmes of at least eight weeks, with data persistence and longitudinal session management.	Functional / Non-functional	Greater effect in programmes ≥ 8 weeks (53, 65); benefits sustained at 6 weeks in executive control (52).
DR5	The AR experience must be multi-user, with shared visualisation and synchronicity among participants.	Functional	Multi-user collaborative AR patterns: shared visualisation, roles, synchronicity (14).
DR6	The system must include an asymmetric monitoring module that provides the teacher or therapist with real-time performance data, with role-differentiated views.	Functional (architecture)	Asymmetric mixed reality with support for teacher decision-making (70); the AHA system integrates a web service that allows parents, teachers and professionals to monitor the child's behaviour during AR activities (61).
DR7	The architecture must allow the recording and remote monitoring of intervention progress.	Functional (architecture)	VR/AR architecture with remote monitoring for ADHD (67); integration of AR with a web application for ADHD monitoring in the AHA project (61).
DR8	Interaction must be anchored to the physical environment (marker-based AR or tangible objects) in order to reduce technical burden and facilitate integration into schools.	Functional / Constraint	AR in an intermediate position of the virtuality continuum, with anchoring to the physical environment (12); tangible AR in ADHD (10).



ID	Design requirement	Nature	Supporting evidence
DR9	The system must record session metrics and be compatible with standardised attention measurement instruments (D2 Test, CPT) and, optionally, with objective sensors (eye tracking, EEG).	Functional / Non-functional	D2 Test in serious games (46) ; clinical scales in digital therapy (48) ; eye tracking (56) ; EEG markers (49) ; attentional vigilance with CPT (59) .
DR10	Sensory design must be controlled so as to sustain attention without inducing cognitive overload in group activities.	Non-functional	Cognitive load negatively moderates the attention–emotional regulation pathway in multisensory AR for ADHD (68) ; risk of cognitive overload in collaborative AR (13) .
DR11	The development process must incorporate families and therapists as active stakeholders in design and validation.	Engineering process	Family involvement improves efficacy and the transfer of skills (35) ; school–home collaboration with sustained benefits (37) ; the AHA system was designed as a shared space for parents, teachers and experts close to the child (61) .
DR12	Game mechanics must foster frustration tolerance and emotional control as a design variable.	Functional / Non-functional	Improvement in frustration tolerance, attention and execution times in AR serious games with motion capture for ADHD (62) ; improvements in emotional regulation with immersive social training (15) .

Discussion

The results outlined above admit a joint reading along three lines. First, the collaborative dimension shows a consistent effect on attention in children with ADHD, moderate in magnitude and stable across school-based and digital interventions, which supports treating collaboration as a design mechanism rather than as an accessory feature of the activity. Second, the immersive dimension displays an asymmetric evidence base: AR accumulates evidence of feasibility and effect in this population, but through designs of limited statistical power, whereas the largest effect magnitudes come from VR, a platform that replaces rather than preserves the physical environment. Third, the two dimensions have been investigated in parallel rather than jointly, so that the parameters of collaborative process and the affordances of AR have not been combined within a single system evaluated with this population. This configuration of the evidence is what justifies expressing the synthesis as design requirements: each requirement aggregates findings that are individually supported but whose combined effect has not yet been measured, and is therefore formulated to be verified rather than assumed.



Research gap, certainty of the evidence and scope

The cross-cutting finding of the review is that the explicit combination of structured collaborative strategies, AR and ADHD remains a research gap even in the most recent literature of the period reviewed ([13](#), [14](#), [15](#), [16](#), [72](#)). On the basis of the design, sample size and consistency of the findings of the studies in each group, the certainty of the evidence can be characterised by category: the evidence on digital and immersive interventions in ADHD (categories 4 and 5) is of moderate certainty, supported by multiple meta-analyses with large samples ([53](#), [59](#), [64](#)); the evidence on collaborative strategies applied to ADHD (category 2) is of moderate certainty, sustained by controlled trials ([36](#), [37](#)) and a recent meta-analysis ([34](#)); and the evidence on the complete intersection (category 6) is of low to very low certainty, with scarce studies, small samples and predominantly non-randomised designs.

As with any review of an emerging field, this work has a bounded scope that should be made explicit: (a) the search was restricted to publications in English and Spanish; (b) since it draws on peer-reviewed literature, there is a risk of publication bias, given that positive results are more likely to be published; (c) the methodological heterogeneity of the corpus precludes quantitative meta-analysis and limits direct comparability between studies, which is why a structured narrative synthesis in accordance with SWiM was adopted; and (d) there is a platform asymmetry in the quantitative evidence: the meta-analytic effect sizes of the immersive dimension come mainly from VR studies ([59](#), [64](#)), and their transfer to AR cannot be assumed without empirical verification, which is precisely one of the reasons why controlled primary studies of collaborative AR, such as the one this review underpins, are required. These boundaries limit the generalisation of the clinical findings but do not affect the derivation of requirements: each DR in Table 2 is traceable to verifiable sources and is formulated to be tested empirically during the validation of the system that implements it.

Conclusions

Collaborative strategies have a significant and consistent impact on improving attention in children with ADHD, with a moderate effect size ($d = -0.33$) according to the most recent meta-analytic evidence ([34](#), [53](#)). AR is situated at an intermediate point of the desktop–VR continuum, combining physical anchoring with moderate immersion, which supports its relevance for school settings ([12](#)), with its own evidence consistent in direction—meta-analytic superiority in special needs populations ([57](#)) and interventions validated in reading, cognition and play—although predominantly qualitative and pilot in nature; VR, included as adjacent evidence, establishes the upper bound of the immersive dimension with $d = -1.05$ on sustained attention ([64](#), [65](#)), a magnitude whose transfer to AR must be verified empirically. The central contribution of this review, as against existing effectiveness reviews, is the translation of that evidence into twelve verifiable and traceable design requirements (DR1–DR12) covering the collaborative process (group sizing according to the task, roles, involvement of families and therapists), the system architecture (multi-user with shared visualisation, role-based asymmetric monitoring, remote monitoring, longitudinal persistence) and measurement instrumentation (session metrics, compatibility with the D2 Test and CPT, objective sensors). These three results come from bodies of evidence appraised

separately—collaborative interventions without AR, predominantly individual AR applications and VR systems— so that their convergence supports the formulation of design requirements, not an estimate of the efficacy of collaborative AR systems for children with ADHD, whose empirical verification remains pending.

The intersection of collaboration engineering, AR and ADHD constitutes an open research gap: the closest studies address only two of the three components (14, 15, 72). The ITCL framework (72), the principles of collaboration engineering (4, 5) and the requirements derived here provide the basis for closing it.

Future research should advance in three directions: (1) designing and validating AR applications that implement requirements DR1–DR12 in studies with randomised comparison groups and samples of $n \geq 30$; (2) adopting standardised neuropsychological measurement instruments complemented by objective measures of behaviour during AR use; and (3) analysing the collaborative component as a moderating variable of the effect of AR, separating the specific contribution of the collective dimension from the general effect of immersive technology. The derived requirements directly underpin the development of the collaborative AR application proposed as the central technological product of the thesis “Collaborative strategies to improve attention in children with ADHD through augmented reality”, Master’s programme in Computing, Universidad del Cauca. To advance in this direction, requirements DR1–DR12 derived in this work are currently being implemented in NeuroRuta, a collaborative AR application developed within the research that frames this review, whose empirical validation process contemplates the measurement of attention through standardised instruments and the automatic recording of session metrics during interaction. This development will make it possible to test empirically the requirements proposed here and to provide the primary evidence on collaborative AR whose absence constitutes the identified gap, closing the cycle between the derivation of requirements from the literature and their verification in a real system.

Author contributions

Conceptualisation: J. S. Hurtado Campo, C. A. Collazos Ordoñez; Data curation: J. S. Hurtado Campo; Formal analysis: J. S. Hurtado Campo; Funding acquisition: J. S. Hurtado Campo; Investigation: J. S. Hurtado Campo; Methodology: J. S. Hurtado Campo, C. A. Collazos Ordoñez; Project administration: J. S. Hurtado Campo; Supervision: C. A. Collazos Ordoñez; Validation: C. A. Collazos Ordoñez; Visualisation: J. S. Hurtado Campo; Writing – original draft: J. S. Hurtado Campo; Writing – review and editing: C. A. Collazos Ordoñez, J. S. Hurtado Campo.

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Conflicts of interest

The authors declare that they have no conflicts of interest in the writing or publication of this article.

Ethical implications

The authors have no ethical implications to declare in the writing and publication of this article. The study is a systematic review of published literature and did not involve intervention with human beings or the handling of personal or sensitive data.

Data availability

The individual characterisation of the included studies is provided as supplementary material in spreadsheet format; the extraction forms are available upon request from the corresponding author.

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