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A USER-CENTERED CONCEPTUAL FRAMEWORK FOR DESIGNING AUGMENTED REALITY OBJECT- RECOGNITION INTERVENTIONS TO SUPPORT EARLY COMMUNICATION IN CHILDREN WITH AUTISM

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Abstract:

Early communication difficulties remained a significant developmental challenge for children with autism spectrum disorder (ASD), often affecting learning engagement, social interaction, and functional independence. While Augmented Reality (AR) has gained attention as a promising intervention technology due to its interactive and context-aware capabilities, many existing AR-based solutions for autism are application-driven and lack a systematic design foundation grounded in user needs. This limits their consistency, scalability, and effectiveness across diverse learning contexts. This study proposed a user-centered conceptual framework to guide the design of AR-based object-recognition interventions aimed at supporting early communication development in children with autism. Grounded in User-Centered Design (UCD) principles, the framework integrates user needs, sensory-aware interaction design, and object-recognition mechanisms to align with the cognitive, communicative, and sensory characteristics of children with ASD. The framework was operationalized through the development of an AR prototype and examined through structured observation of children's interaction and quantitative usability evaluation by parents. Findings indicated that a framework-driven, user-centered approach supported engagement, attention, and object-function understanding, which are foundational to early communication

skills. Parents' evaluations further validated the frameworks' usability, learnability, sensory compatibility, and perceived communication support. Variations in user interaction outcomes also highlighted important framework refinement areas, including adaptive scaffolding and error-handling mechanisms for learners with lower communication readiness. This study contributed by offering a reusable and transferable conceptual framework that extends beyond a single application implementation. The framework provides practical guidance for educators, therapists, and developers in designing AR-based communication interventions for children with autism and establishes a foundation for future research in inclusive and technology-supported special education.

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Augmented Reality; Autism Spectrum Disorder; Conceptual Framework; Early Communication; User-Centered Design



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Introduction

Early communication development plays a critical role in children's cognitive growth, social interaction, and participation in learning environments. For children with ASD, difficulties in early communication often manifest through limited expressive language, challenges in receptive understanding, reduced joint attention, and difficulty linking objects to their functional meanings (Maksimović, S., Marisavljević, M., Stanojević, N. et al., 2023). These challenges can significantly affect their learning readiness, daily functioning, and long-term educational outcomes. Consequently, early intervention strategies that effectively support communication development are widely regarded as essential within special education and therapeutic contexts.

Conventional communication interventions for children with autism frequently rely on visual-based supports, such as picture cards, symbol systems, or structured routines (Bateman, K. J., Wilson, S. E., Gauvreau, A et al., 2023). While these approaches provide important scaffolding, they are typically static and offer limited opportunities for interaction, contextual learning, or adaptive feedback. As a result, children may struggle to generalize learning concepts beyond structured settings or to sustain engagement during learning activities (Vivanti, G., Rogers, S. J., Dwyer, P., & Rivera, S., 2022). This has led educators and researchers to increasingly export technology-supported interventions that can provide interactive, engaging, and individualized learning experiences tailored to the diverse needs of children with autism.

Among emerging educational technologies, AR has gained attention for its ability to overlay digital content onto real-world objects, creating interactive and context-aware learning environments. According to Fuentes, C., Gómez, S., De Stasio, S. et al. (2025), AR has particular potential in autism intervention due to its visual strengths, capacity for multimodal

engagement, and ability to support concrete learning experiences. By presenting visual, auditory, and interactive cues simultaneously, AR may help children with autism better understand object-function relationships, sustain attention, and engage in communication-related behaviors. These affordances position AR as a promising tool for supporting early communication development.

Despite growing interest in AR-based interventions for autism, existing studies and applications are largely application-driven and focused primarily on technological features or short-term usability outcomes (Hirzle, T., Müller, F., Draxler, F. et al, 2023). Many AR solutions are developed without a systematic design framework that explicitly incorporates user needs, sensory considerations, and communication objectives (Mendoza-Ramírez, C. E., Tudon-Martinez, J. C., Félix-Herrán, L. C., et al., 2023). This lack of a coherent user-centered design foundation limits the transferability, scalability, and consistency of AR interventions across different educational and therapeutic contexts. Moreover, without a guiding framework, design decisions may not adequately address the heterogeneity of children with autism, particularly in relation to sensory sensitivities, attention span, and communication readiness.

To address these limitations, there is a need for a structured user-centered conceptual framework that can guide the design of AR-based interventions for early communication in children with autism. Such a framework should integrate principles of UCD, communication-focused learning objectives, and sensory-aware interaction design, ensuring that AR applications are not only technologically functional but also pedagogically meaningful and developmentally appropriate.

In response to these needs, the present study proposed a user-centered conceptual framework for designing AR-based object-recognition interventions to support early communication in children with autism. The framework emphasizes alignment between user needs, interaction design, and object-recognition mechanisms to support foundational communication skills. By operationalizing and empirically examining the framework through an AR prototype, this study seeks to contribute a robust and transferable design foundation that can inform future AR-based interventions in special education and autism-related contexts.

Literature Review

Early Communication Challenges in Children with Autism

Early communication development is a foundational component of learning, social participation, and adaptive functioning in childhood. Children with ASD frequently experience delays and difficulties in both expressive and receptive communication, which may include limited verbal output, challenges in understanding spoken languages, and reduced use of gestures or symbols (Vogindroukas, I., Stankova, M., Chelas, E. N., et al., 2022). These communication challenges are often associated with difficulties in joint attention, imitation, and symbolic processing, all of which are essential for early language acquisition and functional learning.

A key aspect of early communication difficulty in children with autism lies in understanding objects and their functional meanings within everyday contexts. Many children with ASD struggle to associate objects with their intended use or communicative labels, which can hinder vocabulary development and reduce opportunities for meaningful interaction. These challenges can also affect learning readiness, as children may find it difficult to engage with instructional materials that rely on abstract representation of verbal explanation alone (Bhat, A. N., Boulton,

A. J., & Tulsy, D. S., 2022). Consequently, interventions that support object recognition and contextual understanding are particularly important in early autism interventions and special education settings.

Technology-Supported Communication Interventions for Autism

Technology-supported interventions have increasingly been adopted in autism education due to their ability to offer structured, reputable, and visually engaging learning environments (Kamid, K. A., 2025). Digital tools such as mobile applications, computer-based programs, and interactive games are often designed to support communication by presenting information through visual and auditory channels, reducing reliance on verbal instruction alone. These approaches have been shown to enhance motivation, reduce anxiety, and provide consistent learning routines, which are beneficial for children with autism.

However, AlGerafi, M. A., Zhou, Y., Oubibi, M., and Wijaya, T. T. (2023) mentioned that existing technology-based interventions also present limitations. Many tools are designed as standalone applications to prioritize content delivery rather than interaction quality or user experience. In some cases, learning activities are highly scripted, offering limited adaptability to individual differences in attention span, sensory sensitivity, or communication readiness. Without careful design consideration, technology-based interventions may inadvertently increase cognitive loads or sensory overstimulation, reducing their effectiveness for certain learners. These challenges highlight the importance of design approaches that move beyond functionality and explicitly address user needs and learning context.

Augmented Reality in Autism and Special Education

AR has emerged as a promising technology in special education due to its capacity to blend digital information with the real-world environment (Vairamani, A. D., 2024). By overlaying visual, auditory, and animated content onto physical objects, AR supports contextual learning and may enhance understanding by linking abstract concepts to tangible experiences (Cheng, Y., & Bololia, L., 2024). For children with autism, AR's visual strengths and interactive nature align well with learning preferences that favor concrete and visually rich representations.

Research on AR-based interventions for autism has reported positive outcomes in areas such as attention, engagement, task completion, and concept comprehension (Fuentes, C., Gómez, S., De Stasio, S., & Berenguer, C., 2025). AR has been used to support social skills training, object recognition, and learning of daily routines by providing immediate visual cues and interactive feedback. These affordances suggest that AR can facilitate object-function understanding and encourage communication-related behaviors, particularly when learning activities are grounded in real-world contexts.

Despite these advantages, much of the existing AR research in autism remained application-focused. Studies often emphasized technological novelty or short-term disability outcomes with limited discussion of the underlying desire rationale or pedagogical alignment. As a result, many AR solutions are difficult to generalize or adapt to different learning environments, user groups, or educational objectives (Koumpouros, Y., 2025).

User-Centered Design in Educational Technology for Autism

UCD emphasizes the systematic involvement of end users throughout the design and development process to ensure that the technologies are usable, meaningful, and contextually appropriate (Magkafa, D., 2022). In the context of autism-focused educational technology, UCD is particularly important due to the heterogeneity of user needs, including differences in cognitive ability, sensory processing, communication level, and learning preferences.

Applying UCD principles in autism design interaction encourages collaboration with key stakeholders such as educators, therapists, parents, and children themselves. This approach supports the development of sensory-aware interfaces, simplified interaction flows, and adaptive feedback mechanisms that reduce cognitive and sensory burden. UCD also promotes iterative refinement, allowing design decisions to be informed by real-world use rather than assumptions about user behavior. However, while UCD has been widely advocated in educational technology, its application within AR-based autism interventions is often implicit rather than systematically articulated through a conceptual framework.

The review of existing literature reveals three key gaps. First, early communication challenges in children with autism remain insufficiently addressed by interventions that explicitly support object recognition and functional understanding in context-rich environments. Second, although AR has demonstrated potential in autism education, many AR-based solutions are application-driven and lack a consistent design foundation. Third, while UCD principles are recognized as valuable, there is a limited presence of reusable user-centered conceptual frameworks that guide the design of AR interventions for early communications support.

This gap highlighted the need for a structured framework that integrates UCD principles with AR-based object recognition to support early communication in children with autism. A framework-driven approach can provide theoretical coherence, design consistency, and practical guidance, enabling developers and educators to move beyond isolated application development towards more systematic and transferable intervention design. Addressing these needs forms the basis for the present study, which proposed and empirically examined a user-centered conceptual framework for AR-based communication interventions in autism education.

Conceptual Framework Overview

This study proposed a user-centered framework that aligns user needs, user-centered design principles, and AR-based object-recognition intervention to support early communication in children with autism. As illustrated in Figure 1, the framework begins with understanding children's communication abilities and sensory characteristics, which informed the application of structured interaction design principles. These principles guide the development of an AR object-recognition intervention, which is then examined through observed interaction outcomes and usability evaluation. Figure 1 illustrated the structural relationships among framework domains and their intended communication-support mechanisms.

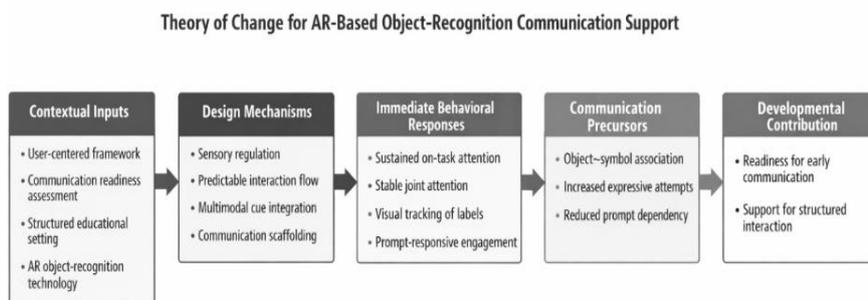


Figure 1: User-Centered Framework For AR-Based Object-Recognition Intervention

Theory of Change

To clarify the hypothesized mechanism linking AR design features to communication precursors, a Theory of Change model was developed (see Figure 2). The model illustrated how user-centered sensory regulation and predictable interaction flow are hypothesized to activate multisensory alignment and scaffolded engagement, leading to observable communication precursors such as sustained attention, joint attention stability, vocabulary mapping, and expressive attempts.

Figure 2: Theory Of Change For AR-Based Communication Support



Methodology

Study Design

This study adopted a design-based research (DBR) approach grounded in User-Centered Design (UCD) principles to develop, operationalize and evaluate a conceptual framework for AR-based object-recognition interventions to support early communication in children with autism. The study was conducted in three phases:

- i. Conceptual framework development and expert validation
- ii. Framework-to-prototype operationalization
- iii. Feasibility evaluation through child observation and parent usability assessment

The objective was not to establish clinical efficacy but rather to examine whether the operationalized framework components generated observable patterns consistent with intended communication-support mechanisms.

Conceptual Framework Development and Validation

The conceptual framework was derived from a systematic synthesis of literature on AR in autism intervention and communication development, and user-based findings obtained from prior needs analysis involving educators and caregivers of children with ASD. The framework integrates three primary domains which included:

- i. User needs (communication readiness, sensory sensitivity, attention profile)
- ii. User-centered interaction design (predictability, simplicity, multimodal feedback)
- iii. AR-based object-recognition mechanisms (real-time visual overlay and audio prompts)

To ensure content validity, the framework underwent structured expert review by experts in special education, autism intervention, and human-computer interaction. Feedback focused on theoretical coherence, classroom feasibility, sensory appropriateness, and communication scaffolding mechanisms. Revisions were incorporated prior to prototype development. This phase established content and construct-level validation of the framework prior to implementation testing.

Framework-to-Prototype Operationalization

The expert-validated conceptual framework was translated into a functional AR prototype through systematic mapping of theoretical constructs to concrete system-level features. The objective of this translation process was to preserve alignment between framework domains, intended communication constructs, and observable interaction behaviours.

Each framework component was explicitly mapped to system-level implementation features, as summarized in Table 1.

Table 1: Framework-to-Prototype Mapping

Framework domain	Framework Component	Intended Communication	Prototype Implementation
User Needs Adaptation	Sensory regulation	Sustained attention	Reduced animation intensity and moderated audio output
Interaction Design	Predictable interaction flow	Joint attention stability	Consistent scanning feedback and stable visual overlays
AR Mechanism	Object-symbol association	Vocabulary mapping	Real-time visual labelling synchronized with audio naming cues
AR Mechanism	Communication scaffolding	Expressive attempts	Guided prompts and structured reinforcement flow

The prototype enabled children to scan real-world objects using a mobile device and receive contextualized multimodal cues, including simplified animations, visual labels, and audio prompts. Design decision prioritized cognitive load reduction, sensory appropriateness, and interaction consistency to support sustained engagement and symbolic association.

Importantly, the prototype functioned as an implementation vehicle for evaluating the operational coherence of the conceptual framework rather than as a standalone intervention efficacy study. The evaluation aimed to examine whether the translated design features caused observable behaviours consistent with the framework's hypothesized communication precursors.

Participants and Settings

A purposive sample of N=4 children diagnosed with ASD participated in the feasibility evaluation. Participants were recruited through the Autism Research Laboratory at Universiti Kebangsaan Malaysia (UKM), where they were already enrolled in structured intervention programs.

All children had been previously diagnosed by qualified clinical professionals prior to their enrollment in the laboratory's intervention services. Thus, diagnostic verification was established independently of the present study.

Participant selection for the observation sessions was coordinated by the Autism Research Laboratory to minimize disruption to the children's existing intervention schedules. Children were randomly assigned by laboratory administrators from those meeting the inclusion criteria to reduce potential selection bias and maintain routine continuity.

Inclusion criteria were:

- i. Documented ASD diagnosis confirmed through prior professional clinical assessment
- ii. Enrolled in ongoing intervention programs at the laboratory
- iii. Ability to engage in short, guided learning activities (approximately 10-15 minutes)
- iv. Written parental consent

The participating children demonstrated varying communication readiness levels, ranging from minimal verbal expression to emerging functional language use.

AR sessions were conducted in a familiar classroom environment within the laboratory to minimize sensory disruption and reduce environmental stress. Each child participated in one structured interaction session lasting approximately 10-15 minutes. Sessions were facilitated by educators familiar with the children's communication profiles and trained in standardized prompting procedures to ensure procedural consistency across observations.

Four parents (N=4) completed a usability questionnaire following observation or review of their child's interaction with the prototype.

Data Collection Procedures

Structured Observation

Child interaction was assessed using a structured, non-participant observational protocol aligned with the framework's intended communication constructs. The observation dimensions were derived from early communication and autism intervention literature, particularly constructs related to sustained attention, joint attention, symbolic association, and expressive attempts.

The following behavioural dimensions were recorded:

- i. Sustained attention (duration of on-task engagement)
- ii. Interaction independence
- iii. Responsiveness to visual/audio cues
- iv. Communication attempts (verbalization, gesture, pointing)
- v. Assistance required (prompt frequency)
- vi. Task completion

Predefined behavioural indicators were used to enhance consistency during live observations. Observations were documented in real time using structured recording sheets during each session to minimize recall bias.

Given the feasibility-oriented scope of the study and small sample size, the observational protocol was intended to capture descriptive behavioural alignment with framework mechanisms rather than to support inferential statistical generalization.

The structured observation instrument is available from the corresponding author upon reasonable request.

Parent Usability Questionnaire

Parents completed a structured usability questionnaire informed by established educational technology usability principles and aligned with ISO 9241-11 standards (Bevan, N., Carter, J., and Harker, S., 2015) which conceptualize usability in terms of effectiveness, efficiency and user satisfaction. The questionnaire assessed six domains such as satisfaction, ease of use, learnability, sensory compatibility and communication support. Items were rated using a 5-

point Likert scale (1= strongly disagree, 5=strongly agree). Domain-level mean scores were calculated to summarize parental perceptions.

The instrument was content-aligned with the framework components to ensure construct relevance. AS the study was exploratory and feasibility-focused, the questionnaire was used for descriptive evaluation rather than formal psychometric validation.

The questionnaire instrument is available from the corresponding author upon reasonable request.

Data Analysis

Data were analyzed descriptively. Observational data were summarized using frequency counts and behavioural pattern comparison across participants. Meanwhile, questionnaire responses were analyzed using mean scores per domain.

Given the exploratory and feasibility-oriented nature of the study and the limited sample size, inferential statistical testing was not conducted. Findings were interpreted in relation to the framework's intended mechanisms to assess alignment between theoretical design principles and observable communication-related behaviours.

Results and Discussion

Observational Outcomes

Across all four participants, sustained engagement ranged between 13-15 minutes, with all participants completing the full interaction session. Detection behaviours were minimal to occasional and did not prevent re-engagement. Joint attention behaviours were observed consistently, with participants, visually tracking scanning sequences and AR overlays. Variation were observed primarily in prompt dependency rather than attentional disengagement.

Object-symbol mapping behaviour were rpresent across participants, evidenced by consistent cisual label attention and synchronized response to audio cues. Expressive output varied according to baseline communication readiness, ranging from spontaneous verbal production (P1) to gesture-dominant responses (P4). Importantly, no participant exhibited withdrawal from interaction.

These patterns demonstrated behavioural consistency with the frameworks' intended communication-support mechanisms (see Table 2).

Table 2: Observed Communication-Behaviours During AR Interaction

Participant	On-Task Duration	Distraction Level	Joint Attention Stability	Prompt Dependency	Object-Symbol Mapping	Expressive Output
P1	~15 min	Minimal	High fixation, immediate response	Low	Consistent label attention, immediate audio response	Spontaneous+prompted verbal
P2	~14-15 min	Minimal	High fixation, immediate response	Low	Consistent label attention, immediate audio response	Prompted verbal
P3	~13-14 min	Occasional	Moderate fixation, delayed response	Moderate	Present label attention, delayed audio response	Limited verbal
P4	~13-15 min	Brief episode	Moderate-high fixation, responsive	Low-Moderate	Present label attention, responsive	Gesture-dominant

Parent Usability Evaluation

Parent evaluation provided complementary evidence supporting the framework's applicability. Overall usability ratings were high, indicating positive perceptions of the interventions' clarity, learnability, and suitability for children with autism, as shown in Table 3.

Table 3: Parent Usability Outcomes

Usability dimension	Mean score
Satisfaction	4.47
Learnability	4.27
Ease Of Use	4.00
Sensory Compatibility	4.20
Communication Support	4.40
Error Handling	3.60
Overall Usability	4.42

Note: Scores based on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree)

Parents rated high perceived usability across domains, particularly satisfaction, communication support, and sensory compatibility, suggesting that the intervention aligned well with children's learning needs and sensory preferences. Slight variation was observed in sensory compatibility and system reliability, through overall ratings remained above 4.0, indicating favourable prototype acceptance.

Collectively, the findings provide preliminary empirical support for the proposed user-centered framework. The findings indicate that an AR-based object recognition intervention design using user-centered and sensory-aware principles can support engagement, attention, and communication-related behaviors in children with autism. At the same time, the results underscore the need for adaptive scaffolding and clearer feedback mechanisms to better accommodate diverse learners' needs.

Limitation

This study has several limitations. The feasibility evaluation involved a small purposive sample and single-session exposure, limiting generalizability. Observational data were descriptive in nature and not intended for inferential statistical analysis. Furthermore, the study examined framework operational alignment rather than long-term intervention efficacy. The findings should therefore be interpreted as preliminary evidence supporting conceptual coherence rather than definitive clinical validation.

Conclusion

The study proposed and empirically examined a user-centered conceptual framework for designing AR-based educational interventions to support early communication development in children with ASD. In contrast to application-driven AR solutions (Hakim, I. N. A., & Mohamad, U. H., 2024), the framework emphasizes the integration of user needs, sensory-aware interaction design, and communication-oriented learning objectives within a structured and theoretically grounded design foundation.

Operationalization of the framework through an AR-based object-recognition prototype demonstrated behavioural patterns consistent with sustained engagement, joint attention stability, and object-symbol mapping, precursors to early communication development. Observational outcomes and parents' usability evaluations provided convergence evidence that the framework aligns well with the sensory, cognitive, and communication characteristics of children with autism. At the same time, variations in interaction outcomes highlighted the importance of adaptive scaffolding and for flexible and scalable frameworks rather than fixed or one-size-fits-all solutions.

The primary contribution of this study lies in the development of a reusable and transferable conceptual framework that extends beyond a single application implementation. By shifting focus from a single application to a reusable design foundation, the study extends current knowledge in educational technology and special education by offering structured guidance for designing AR-based communication interventions. The proposed framework provides practical value for educators, therapists, and developers seeking to create inclusive, context-aware, and user-centered learning tools for children with autism.

In conclusion, this research underscores the importance of framework-driven design in advancing the effectiveness and sustainability of technology-supported interventions in autism education. The proposed framework establishes a foundation for future research and development supporting continued exploration of AR as a meaningful and inclusive tool for early communication intervention. Future research should expand sample diversity, incorporate longitudinal evaluation, and examine adaptive mechanisms to further refine and validate the frameworks' scalability and sustained educational impact.

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Ethics Statement: The study was conducted within an educational technology-design context consistent with minimal-risk instructional practice and adhered to university research governance procedure. No clinical or medical procedures were involved. Written informed consent was obtained from all parents or legal guardian. Sessions were closely supervised to monitor for discomfort or sensory overload. All data were anonymized prior to analysis, securely stored, and used solely for academic research purposes.

Author Contribution Statement: All authors contributed significantly to the development of this manuscript. Intan Nadiah handled data collection, analysis, and interpretation of results. Ummul Hanan Mohamad was responsible for the conceptualization, methodology, and overall supervision of the study, as well as contributing to the literature review, drafting, and critical revision of the manuscript.

Generative AI tools were used solely to assist with language refinement and clarity of expression during manuscript preparation. All study design, data collection, interpretation, and reference verification were conducted independently by the authors.

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