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AI-Driven Multi-Modal Framework: Expanding Comfort Zones for Autistic Children

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Abstract

Autistic children often rely on familiar routines, which can limit exposure to new social, sensory, and creative experiences. This paper presents a multi-modal framework that integrates augmented reality (AR), virtual reality (VR), interactive storytelling, and interpretable AI-based adaptation to support the gradual expansion of autistic children's comfort zones. The paper does not report a completed intervention or effectiveness trial. Instead, it combines an integrative review of autism-support and creative-technology literature with a preliminary qualitative needs assessment conducted in Saudi Arabia to derive design requirements, localise the framework, and clarify how its components are linked. The proposed architecture is organized around five connected elements: narrative orchestration, AR experiences in familiar spaces, VR-based social rehearsal, state-based AI scaffolding, and caregiver-supported real-world transfer. The manuscript further specifies functional creative-media modules, a music sandbox and a digital art studio, and explains how challenge level, sensory load, and pacing can be adjusted through transparent adaptation rules. This paper proposes a design methodology and ethical framework, establishing a theoretical basis for future empirical validation of AI-driven transitions in ASD support.

Keywords Autism; Comfort zones; Augmented reality; Virtual reality; Artificial intelligence; Interactive storytelling

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Introduction

Autism spectrum disorder (ASD) is commonly associated with differences in social communication, sensory regulation, and patterns of restricted or repetitive behaviour (Parsons & Cobb, 2011). Many autistic children rely heavily on predictability, familiar environments, and repeated routines. Although this preference can reduce anxiety, it can also limit opportunities to engage with new people, places, sensory inputs, and creative tasks that are important for broader development.

Educators, therapists, and parents often struggle to determine how to introduce novelty without triggering distress. One common therapeutic principle is graded exposure, meaning that a child is supported to encounter manageable amounts of change step by step rather than all at once. In practice, however, real-world environments are difficult to control. Noise, social unpredictability, unfamiliar sensory cues, and sudden changes in task demands can easily overwhelm a child before meaningful learning takes place (Bai et al., 2015).

Existing interventions often address only one modality or one outcome at a time. Some focus on AR, others on VR, and many are designed for narrow therapeutic objectives rather than for a broader developmental pathway that links familiar environments, immersive rehearsal, sensory customization, and real-world transfer. This paper proposes the AI-Driven Multi-Modal Framework, an integrated approach designed to gradually expand the comfort zones of autistic children. While this paper focuses on the theoretical architecture, the framework's parameters were informed by preliminary design consultations with practitioners, as noted in the acknowledgements. The purpose of the manuscript is to articulate that model clearly, explain the methodological basis on which it was constructed, and show how preliminary stakeholder evidence informed its localization and design logic.

This paper is therefore positioned as a conceptual design manuscript rather than as an efficacy study. Its main contribution is a structured framework that explains how different technologies, design principles, and stakeholder-informed requirements can be linked into a coherent platform for gradually extending comfort zones while preserving predictability, safety, and user agency.

Research Questions

To align the manuscript's purpose with its conceptual and design-oriented methodology, the research questions are framed to guide framework construction rather than intervention testing:

1. How can AR, VR, interactive storytelling, and AI personalization be organized into a coherent platform architecture for the gradual expansion of autistic children's comfort zones?

2. What adaptive mechanisms are required to regulate challenge level, sensory load, pacing, and narrative progression so that novelty remains supportive rather than overwhelming?
3. Which design principles and sensory-customization strategies are needed to accommodate diverse autistic profiles while still encouraging exploration and autonomy?
4. How can preliminary stakeholder insights from the Saudi context inform culturally grounded real-world transfer tasks, caregiver roles, and scenario design within the proposed framework?

Methodology

This conceptual framework was developed using a Design Science Research (DSR) approach, synthesising graded exposure therapy principles with multi-modal interface design requirements. At the introductory level, the methodology combines literature-based problem framing, framework synthesis, and early stakeholder-informed refinement, while Section 3 provides fuller methodological elaboration.

Scope and Significance

The significance of the proposed approach lies in linking three strands that are often treated separately: technology affordances, developmental design principles, and contextualized stakeholder needs. Rather than presenting AR, VR, and AI as isolated tools, the paper argues for a staged system in which familiar-space interaction, immersive rehearsal, adaptive personalization, and caregiver-supported real-world practice are deliberately connected. This positioning also clarifies that the manuscript offers a theoretically grounded and context-sensitive conceptual framework that is intended to guide subsequent prototyping and empirical evaluation.

The rising adoption of home-based technology creates an opportunity for a strong accessible platform which runs on standard devices such as tablets and affordable VR headsets to impact a large number of users. Through its story-based interface which connects AR to VR seamlessly the system promotes skill development and builds resilience and creativity and enhances social participation (Pv et al., 2023).

The following sections first outline the problem of comfort-zone rigidity in autism, then explain the methodological approach used to construct the framework, review the technological foundations that inform it, and present the proposed conceptual architecture. A preliminary Saudi needs assessment is then used to show how the framework was refined for cultural relevance, caregiver usability, and real-world applicability before the paper concludes with implications and future directions.

Background on Autism and Comfort Zones

Children with autism demonstrate intense preferences for routine structures because their sensory processing challenges and anxiety levels often accompany this preference (Bai et al., 2015). Children find stability through their comfort zones which consist of established routines and recognized people and environments. The child will exhibit distress when exposed to minor unexpected changes which include furniture rearrangement school route changes or encountering new social interactions (Mubin et al., 2020).

The Protective Nature of Routine

Routine serves as a protective mechanism which helps children shield themselves from excessive environmental stimulation that could activate their sensory overload response (Dynia et al., 2022). Familiarity reduces uncertainty, enabling some children to focus on tasks like communication or play rather than coping with environmental stress. Rigid adherence to routine rules out potential opportunities for child development. The refusal to participate in new experiences produces barriers for developing skills that include flexible thinking as well as problem-solving together with creativity and social interaction skills (Parsons & Cobb, 2011).

The Tension Between Safety and Growth

A common therapeutic strategy is graded exposure, in which novel experiences are introduced in small, manageable increments under supportive supervision. This approach aims to expand tolerance for change without producing excessive distress. Yet real-world implementation remains difficult because public settings are unpredictable, social encounters evolve quickly, and sensory conditions can escalate faster than a child can adapt (Chung & Chen, 2017). What is needed, therefore, is a controlled but meaningful pathway that preserves safety while gradually widening the child's range of participation.

Emerging Technological Solutions

Digital interventions through mobile applications together with augmented reality games and virtual reality simulations help create an equilibrium between protective needs and developmental requirements (Malinverni et al., 2014). Virtual reality systems create controlled testing areas where researchers can adjust stimuli levels precisely while augmented reality enables learning through digital content placement on actual environments (Boyd et al., 2019). Research evidence supports VR-based social skills training while AR-based scenarios boost task engagement in pretend play and social story comprehension (Cañete & Peralta, 2023; Bai et al., 2015). AI systems possess the ability to adjust these experiences through real-time data collection of user performance and physiological signals which detect stress or comfort levels (Johnson & Picard, 2017).

The Gap in Multi-Modal Integration

The majority of current interventions show restricted focus since they utilize only AR or only VR while neglecting the integration of AI for real-time scenario complexity adjustment (Ghafghazi et al., 2021). Creative assignments that allow children to explore freely tend to get disregarded since they do not fit into the predetermined structured exercises. This paper presents a conceptual framework which unites VR and AR experiences with AI-driven personalization through an interactive storytelling format to support incremental risk-taking and creativity and adaptability (Xing, 2024).

The proposed platform recognizes comfort zones as personalized needs for predictability alongside growth needs for full life engagement and provides innovative safety through this understanding. The subsequent section discusses how autism interventions have employed these separate technologies as a basis for establishing an integrated solution.

Methodology: Design-Science-Informed Conceptual Development

Methodological Positioning

This manuscript adopts a Design Science Research (DSR)-informed conceptual development approach. In design science research, the goal is to create and justify an artefact that addresses a practical problem rather than merely to describe a phenomenon. For the present manuscript, the artefact is the proposed platform architecture and its associated design requirements. Following early design-science phases such as problem identification, objective definition, artefact design, and research communication, the paper develops a conceptual framework rather than a completed, evaluated system (Hevner et al., 2004; Peffers et al., 2007).

The framework was developed in two linked stages. First, an integrative review of literature on autism support, extended reality, sensory design, adaptive learning, and interactive storytelling was used to identify recurring design requirements and technology affordances. Second, a preliminary qualitative needs assessment in Saudi Arabia was used as an early stakeholder-informed requirement-elicitation step. Although this does not constitute a full co-design cycle or prototype evaluation, it introduces participatory design logic into the conceptualization process and localizes the framework for caregiver practice, family routines, and culturally meaningful scenarios (Malinverni et al., 2014).

The methodological output of this paper is therefore design knowledge at the framework level: component relationships, adaptation logic, interface requirements, and context-sensitive transfer mechanisms. It does not claim clinical efficacy, algorithmic validation, or finished prototype performance.

Technology Foundations from the Literature

Mobile applications, virtual reality simulations, augmented reality activities, and adaptive software have all been explored as potential supports for autistic children. In this section, these technologies are reviewed not as isolated tools but as the literature base from which the proposed framework is constructed.

Virtual Reality (VR)

VR enables users to experience virtual worlds that duplicate actual environments or fictional realms (Pv et al., 2023). VR serves autism patients well through its ability to help them practice social interactions such as meeting new people and using public transportation. Researchers explain that VR allows children to practice new tasks in anxiety-reduced conditions because it provides controlled stimuli during repeatable sessions (Parsons & Cobb, 2011). Daily living skills together with social communication abilities and emotional management show improvements when autistic individuals undergo VR interventions (Astafeva et al., 2024). The virtual reality experience delivers such deep involvement that children stay focused on tasks even though they may find the virtual scenarios slightly uncomfortable since the experience resembles a game (Johnson & Picard, 2017).

Augmented Reality (AR)

AR stands out from VR because it adds digital components to the actual environment while maintaining a connection to the real setting (Bai et al., 2015). The capability to generalize skills makes sense because children who use AR to practice social greetings can maintain their practice sessions in their kitchen or living room thus uniting digital practice with real-life environments (Chung & Chen, 2017). Children benefit from AR because the platform utilizes their preference for visual information through features like interactive components and story-based elements which are embedded within regular daily activities (Boyd et al., 2019). According to Cañete and Peralta (2023), AR-based interventions when well-designed produce notable enhancements in both attention and communication abilities.

Artificial Intelligence (AI)

The implementation of AI technology enhances existing modalities by enabling automatic real-time adaptations. An AI system evaluates user conduct such as task duration and performance errors and stress indicators to modify scenario levels or sensory details and narrative paths (Ghafghazi et al., 2021). The system maintains the right level of difficulty that promotes development yet prevents both shutdowns and meltdowns. User modelling through AI-driven approaches enables personalized content delivery to children according to their individual requirements which improves intervention results and decreases the need for continuous therapist observation (Johnson & Picard, 2017).

Toward a Unified Platform

The individual potential of VR, AR and AI emerges well but researchers have not yet developed many joint implementations of these technologies. A child can use AR to interact with story elements at home followed by VR to practice social skills in a simulated playground while an AI system tracks their progress to adjust the following challenges. The combination of extended reality technologies into one continuum allows developers to create an interconnected narrative that expands a child's comfort zone step by step (Mubin et al., 2020).

Autistic children require creative outlets which go beyond the standard focus areas but synergy enables both domains to merge. Tools that enable children to create music and design digital art and build 3D models serve as lower-stress methods to help them discover novelty (Fraca et al., 2020). A platform's interactive art studio enables children to begin with basic colour and sound involvement then advance to sophisticated multi-sensory projects when AI detects their readiness (Lydia et al., 2023). Figure 1 presents a functional UI wireframe of the AR trigger interface, showing how familiar room objects can anchor low-intensity story cues, short prompts, and calm-mode controls within the child's everyday environment.

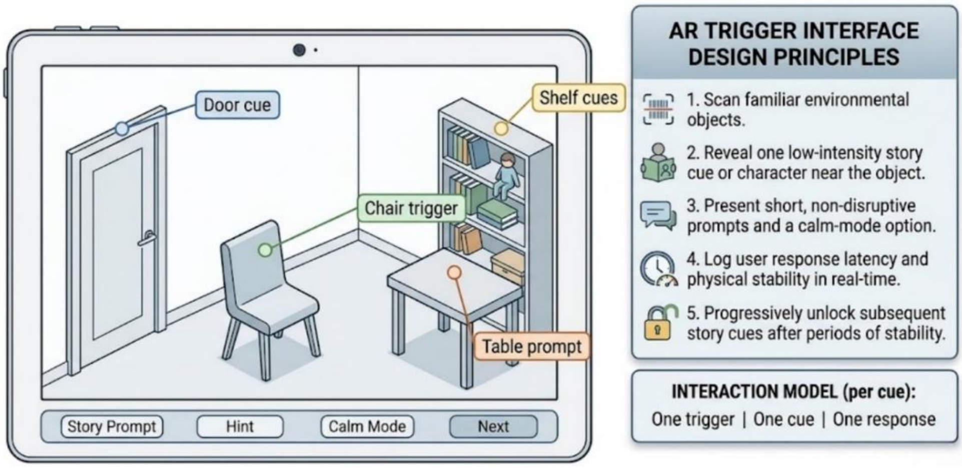

Figure 1. UI Wireframe of AR Trigger Interface

The wireframe clarifies how the familiar-space AR layer can operationalize gentle novelty exposure through one trigger, one cue, and one response cycle before the child is advanced to more demanding modules.

Preliminary Needs Assessment: Stakeholder Insights on Multi-Modal Support in the Saudi Context

To ensure that the proposed conceptual framework addresses the cultural and environmental realities of the intended context of use, a preliminary qualitative needs assessment was conducted in the Kingdom of Saudi Arabia. The purpose of this stage was not to validate the full platform, but to identify friction points experienced by families and practitioners when attempting to expand autistic children's comfort zones, and to use those insights to refine the framework's design logic. The findings reported here directly informed the design principles, localization choices, and feature priorities discussed in Sections 4 and 5.

Participants and Recruitment

A purposive stakeholder sample (N=18) was recruited through collaboration with the King Salman Center for Disability Research and a private pediatric therapy clinic network in Riyadh. Institutional ethics approval was obtained from the Institutional Review Board at King Saud University (KSU-23-0789M), and informed consent was secured from all adult participants and legal guardians in accordance with Saudi national bioethics requirements. The cohort consisted of eight parents/caregivers of children aged 6-12 with formal ASD diagnoses, six therapists/educators working in Saudi rehabilitation and inclusive-education settings, and four verbal autistic children aged 8-10 who participated only in observational playtesting of low-fidelity, non-immersive prototypes.

Data Collection Procedures

Data were collected over four weeks using two modalities. First, two 90-minute semi-structured focus groups were conducted separately with parents and professionals. Discussion topics included current strategies for introducing novelty in Saudi home life, triggers for dysregulation during social and sensory change, and perceived barriers to adopting AR/VR-based support tools. Second, the four child participants completed brief observational sessions using a paper prototype and a simple tablet-based AR marker demo that represented the familiar-space storytelling concept later incorporated into the framework. Observational notes focused on sustained attention, withdrawal, and signs of positive or negative affect.

Summary of Key Findings

Thematic analysis of the focus-group transcripts and observational notes yielded three recurring themes that were sufficiently consistent to influence the platform's architecture: (1) family gatherings as a major barrier to generalization, (2) demand for discreet caregiver control rather than overt therapist-like prompting, and (3) delayed adjustment to novel auditory stimuli. Table 1 presents the preliminary findings and their design implications.

Table 1. Preliminary findings and design implications (Saudi cohort)

Theme Identified	Representative Stakeholder Quote	Implication for Platform Design
1. The "Family Gathering" Barrier	Parent: "He copes at home and school, but when the family gathers at his grandmother's house - smells, loud cousins, new seating - he melts down at the door."	Supports VR rehearsal of majlis and extended-family visits; prioritizes culturally familiar but socially variable scenarios.
2. Demand for Covert Control	Therapist: "Mothers need a tool that lets them guide the child without making family life feel like formal therapy."	Supports narrative-led interaction and silent caregiver adjustments through the dashboard.
3. Sensory Latency to Novel Auditory Stimuli	Observation note: the child covered their ears when soft oud music began, then started tapping with the rhythm after about 95 seconds.	Supports a short processing window before the AI removes novel auditory cues.

Application to the Conceptual Framework

The preliminary needs assessment shaped the framework in several concrete ways. The family-gathering theme directly informed the real-world integration layer and the inclusion of socially meaningful scenarios such as visits to relatives, Jumu'ah gatherings, and Eid-related routines. The demand for discreet caregiver control informed the design of a caregiver dashboard that can silently adjust pacing, difficulty, and sensory load without interrupting the child's story experience. The observed delay in adapting to unfamiliar sound contributed to the AI logic described in Section 4 by introducing a processing window before sensory cues are reduced or withdrawn. In this way, the preliminary data are not peripheral to the manuscript; they are explicitly used to localize and refine the proposed conceptual framework.

Conceptual Framework: An AI-Powered, Multi-Modal Platform

The proposed conceptual framework is organized as a linked progression model rather than a collection of separate features. Interactive storytelling provides the motivational spine of the system; AR introduces manageable novelty in familiar environments; VR supports rehearsal of more demanding social situations; AI personalization regulates difficulty, sensory input, and pacing across modules; and caregiver-supported real-world tasks connect virtual progress to everyday participation. Data from each interaction cycle feed back into the AI layer, which then reshapes the next narrative step, task complexity, and transfer recommendations.

Table 2 synthesizes the framework components, their underlying theory, and the technical scaffold through which each component is operationalized.

Table 2. Synthesis table linking framework components, theory, and technical scaffold

Framework Component	Underlying Theory	Technical Scaffold
AR Exploration	Graded exposure in familiar contexts	AI-regulated visual density and object-trigger thresholds
VR Social Rehearsal	Situated rehearsal; social learning	Adjustable crowd size, dialogue branching, and environmental intensity
Narrative Orchestration	Narrative engagement; guided participation	Branching story arcs, cue sequencing, and supportive prompts
AI Scaffolding	Zone of Proximal Development; adaptive scaffolding	Heuristic state classification with one-parameter adaptation

Creative Media Exploration	Constructionist creativity; sensory exploration	Bounded palette, tempo, track density, and stability gating
Real-World Transfer	Generalization; ecological validity	Caregiver dashboard, quest log, and culturally grounded follow-up tasks

The framework is therefore intended to move the child through a sequence of familiarization, supported exploration, immersive rehearsal, creative-media experimentation, and real-world transfer. To make one adaptation pathway more explicit, Figure 2 presents a flowchart of the AI decision-tree used for volume modulation during moment-to-moment interaction.

Narrative as the Unifying Thread

The framework centers on interactive storytelling because narrative provides continuity, motivation, and emotional meaning across otherwise different activities (Chung & Chen, 2017). Rather than presenting children with disconnected drills, the platform embeds social practice, sensory exploration, and creative experimentation within story arcs that evolve gradually. This structure also supports discreet caregiver facilitation: adults can adjust pacing and support in the background while the child experiences the interaction as part of a coherent story world rather than as a sequence of explicit therapy commands.

AR for Familiar-Environment Exploration

The AR layer uses the child's home, classroom, or other familiar setting as the starting point for novelty exposure (Bai et al., 2015). For example, scanning a family room with a tablet may reveal a virtual character on a bookshelf or trigger a short mission attached to a known object. Because the physical environment remains recognizable, novelty can be introduced without simultaneously increasing environmental uncertainty (Cañete & Peralta, 2023). In the Saudi context, this principle is especially relevant for domestic spaces such as the family sitting room (majlis), where stakeholder feedback highlighted the challenge of preparing children for changing family-gathering dynamics described in Section 3.

VR for Immersive Scenario Training

When a child is ready for more complex rehearsal, the framework transitions to VR scenarios that simulate situations such as classrooms, playgrounds, shops, or family gatherings (Parsons & Cobb, 2011). Within these environments, the child can encounter graded increases in background sound, crowd density, conversational turns, or task demands while remaining inside a controlled and repeatable setting (Pv et al., 2023). This is where the framework addresses higher-intensity social and sensory challenges that would be difficult to stage safely in everyday life.

AI-Driven Personalization and Scaffolding Logic

The AI engine utilises a heuristic-based feedback loop to monitor latency and optional heart-rate input, mapping these signals against a pre-defined threshold of sensory over-stimulation to trigger immediate environment simplification. At this conceptual stage, the manuscript does not claim a trained black-box predictive model. Instead, it specifies an interpretable state-based adaptation logic intended for future prototype implementation.

1. Adjust challenge levels: introduce or reduce characters, background activity, task steps, or puzzle complexity.
2. Personalize story branches: route the child toward more supportive, neutral, or more challenging narrative paths based on current engagement and prior stability.
3. Modulate sensory inputs: tune visual, audio, and haptic intensity so that novelty remains manageable rather than overwhelming.
4. Recommend real-world tasks: generate caregiver-facing suggestions that extend digital progress into everyday life, such as greeting a relative after rehearsing greetings in VR.

The AI engine maintains the user within the Zone of Proximal Development (ZPD) (Vygotsky, 1978) by dynamically adjusting 'scaffolds', such as reducing background noise or simplifying narrative choices, to ensure that the cognitive load matches the child's real-time sensory tolerance, consistent with adaptive scaffolding principles (Chen, 2014).

Conceptual Adaptation Logic

The proposed adaptation logic begins with a weighted child-state estimator that combines behavioural signals such as latency, help requests, completion success, pause duration, and exit behaviour. It then classifies the session into three operational states, regulated, watchful, or overloaded, and applies one-parameter adaptation at a time. In other words, the system should not simultaneously increase crowd size, sound intensity, and task branching. Instead, it should modify a single major variable, observe the response, apply a short hysteresis interval to prevent oscillating adjustments, and preserve a brief processing window before withdrawing unfamiliar auditory cues. This level of technical granularity is intentionally transparent so that caregivers and clinicians can later inspect, override, and refine the adaptive rules. Figure 2 presents the proposed AI decision-tree for volume modulation, showing how behavioural and optional physiological signals are classified into regulated, watchful, and overloaded states, and how each state triggers a controlled volume response under a one-parameter-at-a-time safety rule.

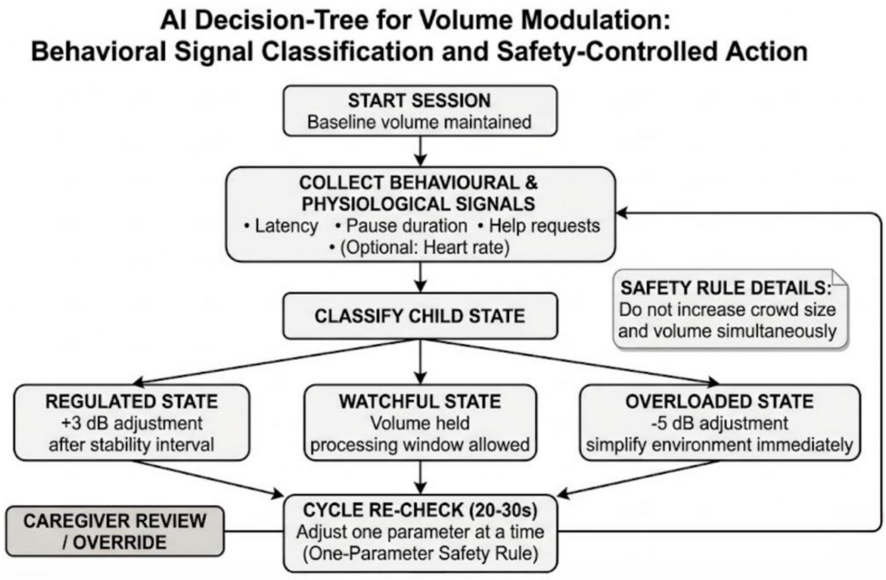

Figure 2. AI Decision-Tree for Volume Modulation Based on Child-State Classification and One-Parameter Safety Control

Integrated Creative Modules

The platform also includes creative exploration tools such as a music sandbox and a digital art studio, which provide lower-pressure opportunities to encounter new sensory and expressive possibilities (Fraca et al., 2020). These modules are important because comfort-zone expansion should not be limited to social compliance. They allow children to experiment with sound, colour, motion, and composition in a self-directed manner while the AI gradually broadens available options in response to growing confidence.

Functional Parameters for the Music Sandbox and Digital Art Studio

To strengthen the creative multimedia contribution of the framework, the music sandbox and digital art studio are defined as functional modules rather than generic examples. The intention is not to claim a final interface implementation, but to specify the operational parameters that future prototypes should contain.

Music Sandbox. The audio module should begin in a low-stimulation mode with one sound source, slow tempo, restricted frequency range, and a capped master volume. Functional parameters include the number of simultaneous tracks, tempo range, rhythmic density, onset spacing between added sounds, timbral familiarity, and the intensity of any accompanying visuals. The AI should increase only one auditory variable at a time and should preserve a short processing window before muting a new cue, so that momentary hesitation is not treated as immediate rejection.

Digital Art Studio. The visual module should provide graded control over palette size, saturation and brightness limits, brush size, stroke speed, animation amplitude, particle density, number of interactive objects, and optional haptic or audio feedback linked to drawing actions. A structured-to-open progression can therefore move from static two-colour composition to richer multimodal creation while keeping the child within a manageable sensory bandwidth. These parameters make the creative-media layer functionally specifiable for later interface design, prototyping, and usability evaluation. Table 3 summarizes the major components of the framework and clarifies how each component contributes to the wider progression model.

Table 3. Multi-modal components of the proposed framework

Component	Modality	Primary Purpose	Example
AR Storytelling	AR	Gentle introduction to new concepts	Searching for virtual characters at home
Immersive Social VR	VR	Controlled scenario practice	Simulating a school hallway with adjustable noise
Creative Exploration	AR/VR	Sensory-friendly self-expression	Digital art studio with adjustable palette and motion; music sandbox with staged track density
AI Personalization	Software	Dynamic difficulty & adaptation	State-based adaptation using behaviour indicators and one-parameter changes
Real-World Integration	Mixed/None	Skill transfer & generalization	Encouraging parent-approved tasks outside the app

Real-World Integration

Real-world integration is the bridge between virtual practice and everyday life. After completing digital scenarios, the child receives caregiver-supported missions that extend the same skill into a familiar offline context, such as greeting a relative, tolerating a new sound cue during a family visit, or completing a short task in a community setting. In the Saudi context, preliminary stakeholder input particularly highlighted preparation for family gatherings, Jumu‘ah visits, and Eid-related social routines. These examples informed the framework’s emphasis on culturally meaningful transfer rather than generic post-session homework.

Figure 3 specifies the adaptation pipeline as a state-based control loop linking behavioural inputs, child-state classification, one-parameter adaptation, caregiver review, and real-world transfer outcomes.

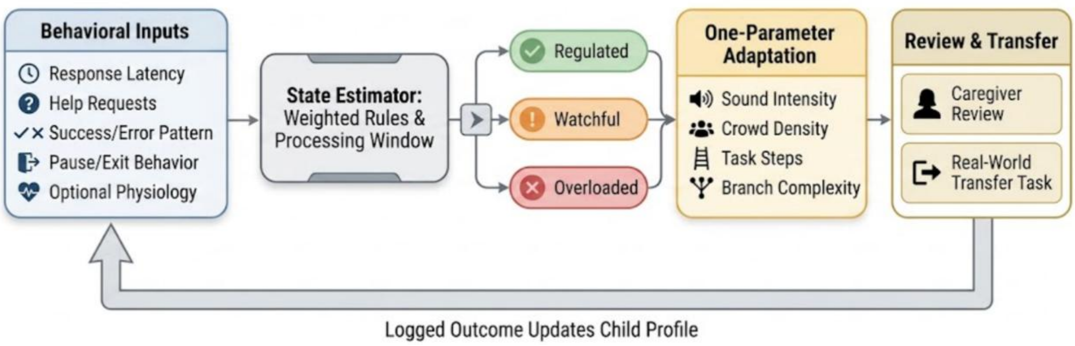

Figure 3. Interpretable AI Adaptation and Real-World Transfer Loop

The following section translates the conceptual framework into concrete platform features, showing how each module operationalizes the framework logic described above.

Key Features of the Platform

The platform features operationalize the conceptual framework through specific modules, interfaces, and progression rules. Each feature is tied to one or more of the framework components already introduced, so this section explains not only what the platform contains but also why each feature exists within the wider architecture.

AR Storytelling in Familiar Spaces

Children begin with AR narratives that unfold in familiar settings such as the home, classroom, or therapy room (Bai et al., 2015). Starting in a known environment reduces contextual uncertainty and allows the child to focus on the introduced novelty rather than on coping with an entirely new setting.

Everyday objects can function as story anchors. For example, pointing a tablet at a chair, doorway, or table may trigger a virtual character, a short mission, or a social cue that advances the narrative.

The platform begins with very simple quests and then gradually adds partners, multiple steps, sound layers, or alternative story outcomes. In the Saudi context, the same logic can be applied to family-sitting-room scenarios to prepare children for changing guest configurations and sensory cues during gatherings.

The familiarity of the physical setting allows the introduced novelty to remain calm, intentional, and developmentally manageable (Chung & Chen, 2017).

VR Social Skills Trainer

Once the child is comfortable with AR-based novelty, the framework transitions to VR scenarios that model more demanding social environments (Halabi et al., 2017). These may include educational spaces, outdoor environments, shops, or culturally relevant family settings.

The AI adjusts crowd size, conversational complexity, noise level, pacing, and task branching so that the same scenario can function at multiple levels of difficulty for different children (Johnson & Picard, 2017).

Because the environment is simulated, the child can rehearse greetings, turn-taking, decision-making, and conflict management repeatedly without facing real social consequences. This repeatability is central to graded progression (Astafeva et al., 2024).

The absence of real-world repercussions in VR makes experimentation safer, especially for children who otherwise avoid unfamiliar social situations after only one negative or stressful encounter.

Sensory-Friendly Creative Tools

Creative modules run alongside AR and VR modules to provide self-directed forms of exploration (Fraca et al., 2020). These modules are not peripheral; they offer an alternative route for comfort-zone expansion through play, experimentation, and authorship, and they are specified here at the level of functional creative-media controls rather than as decorative add-ons.

A digital art studio can allow children to manipulate colour, texture, shape, motion, and scene complexity while still controlling sensory intensity. Relevant parameters include palette size, saturation ceiling, animation amplitude, object count, and optional haptic feedback, which can be widened only when the prior level remains stable.

A music sandbox can begin with a single calm tone or loop and then gradually add instruments, rhythm, volume, or culturally familiar sounds. Relevant parameters include track count, rhythmic density, loudness ceiling, and novelty-cue timing. This staged broadening of the soundscape is particularly relevant to the preliminary finding that some children may need extra processing time before a novel auditory stimulus becomes tolerable.

The AI can introduce new expressive elements gradually as confidence grows, ensuring that creativity remains challenging enough to support development but not so unpredictable that it becomes aversive. In both modules, the adaptation rule is to change one dominant creative parameter at a time and to log whether the child stabilizes, withdraws, or seeks more complexity.

Guided Tasks with Progression

Every feature, from AR stories to VR simulations, follows a structured-to-open trajectory (Cañete & Peralta, 2023).

1. Structured stage: clear instructions, minimal variables, and immediate feedback.
2. Semi-open stage: fewer instructions, optional sub-goals, and moderate complexity.

3. Open-ended stage: greater autonomy, higher variability, and optional stretch challenges calibrated to the child's tolerance.

This structured-to-open trajectory is essential because the framework is designed to widen comfort zones gradually rather than through abrupt exposure. A shopping scenario, for example, may begin with a nearly empty store and later expand into a busier environment with more products, sounds, and interaction points.

Real-World Integration

The connection between virtual accomplishments and offline activities is a core design requirement rather than an optional add-on (Mubin et al., 2020). After digital success, the system should recommend short, parent-approved real-world tasks that mirror the same skill in a familiar setting.

Examples include visiting an actual playground after completing a virtual playground quest, tolerating a new sound cue during a family visit, or practising a greeting with a known relative after a VR greeting scenario.

A daily quest log and caregiver dashboard can be used to review, modify, or defer these recommendations, ensuring that transfer tasks remain realistic for the child's home routine and cultural context.

This transfer mechanism is where the framework responds most directly to stakeholder concerns about real-life usefulness: digital progress should prepare children for participation beyond the screen, not remain trapped within the platform.

Continuous AI Adaptation

The AI receives data from all modules to create individualized learning paths for each child (Ghafghazi et al., 2021). In practice, this means synthesizing engagement data, pacing data, error patterns, avoidance behaviours, and caregiver feedback rather than reacting to a single signal in isolation.

1. Engagement metrics may include time on task, error frequency, pause duration, or help-button use.
2. Where ethically approved and technically feasible, optional camera or wearable data may help estimate distress or excitement, but these should remain consent-based and non-essential (Xing, 2024).

3. The system should reduce stimulation when sustained overload is likely, but it should also allow a short processing window before withdrawing every new sound or visual cue so that the child has time to adapt.

Table 4 maps major platform features to their intended outcomes.

Table 4. Feature-to-outcome mapping

Feature	Intended Outcome	Example
AR Storytelling in Familiar Spaces	Gentle expansion of routine surroundings	Simple scanning tasks become more story-intensive over time
VR Social Skills Trainer	Safe rehearsal of challenging social scenarios	Simulated playground with adjustable group size
Sensory-Friendly Creative Tools	Incremental desensitization to new sounds/colors	Music sandbox expands tempo or track density one parameter at a time; art studio widens colour and motion range progressively
Structured Tasks with Progression	Gradual building of confidence & autonomy	Grocery store scenario from “empty” to “crowded”
Real-World Integration	Reinforced transfer of learned skills to daily life	VR success → actual playground visits recommended

The feature set operates based on the belief that controlled exposure to new experiences at regular intervals helps autistic children develop their ability to manage unexpected situations. We then analyze how these features match design principles which specifically address autistic children's requirements.

Design Principles for Supporting Autistic Children

Designing technology for autism involves both choosing suitable technology and adjusting it to meet user needs (Malinverni et al., 2014). The development of the multi-modal platform followed these fundamental principles:

Personalization and Adaptability

Autism presents differently across children. Some may be sensitive to loud sounds or bright colours, while others may struggle more with open-ended tasks, transitions, or social ambiguity (Dynia et al., 2022). The framework therefore requires adjustable variables rather than a single fixed pathway, and its state-based AI logic is intended to scaffold tasks into a support range rather than impose identical difficulty on all users.

Sensory Customization

Sensory overload is a common challenge (Boyd et al., 2019). The platform should therefore allow brightness, volume, visual complexity, pacing, and cue timing to be personalized at baseline and adapted dynamically during use. For auditory change in particular, the framework incorporates a short processing window before the system interprets defensiveness as overload.

Structured Flexibility

Children with autism often benefit from predictable structures while still needing opportunities to encounter manageable novelty (Chung & Chen, 2017). The framework therefore combines routine-preserving formats with optional extensions and branching challenges.

Positive Reinforcement and Gentle Surprises

The development of beneficial associations toward new things constitutes a fundamental principle. The system immediately rewards children for their steps beyond their comfort zone boundaries (Resnick & Silverman, 2005). Children become curious about their environment when the system reveals hidden story elements after they achieve specific goals. The method converts the fearful reaction to new experiences into a thrilling adventure according to Malinverni et al. (2014).

Parental and Therapeutic Collaboration

Parents together with caregivers and therapists maintain essential roles in this process (Lydia et al., 2023). The caregiver dashboard enables progress tracking while logging real-world achievements and provides manual controls for AI suggestions. Real-world challenges become appropriate through collaborative efforts which also create continuity between digital and offline domains (Mubin et al., 2020).

Figure 4 presents functional wireframes for the Music Sandbox and Digital Art Studio so that the manuscript makes a clearer creative multimedia contribution at the interface level and shows how auditory and visual parameters can be widened gradually rather than all at once.

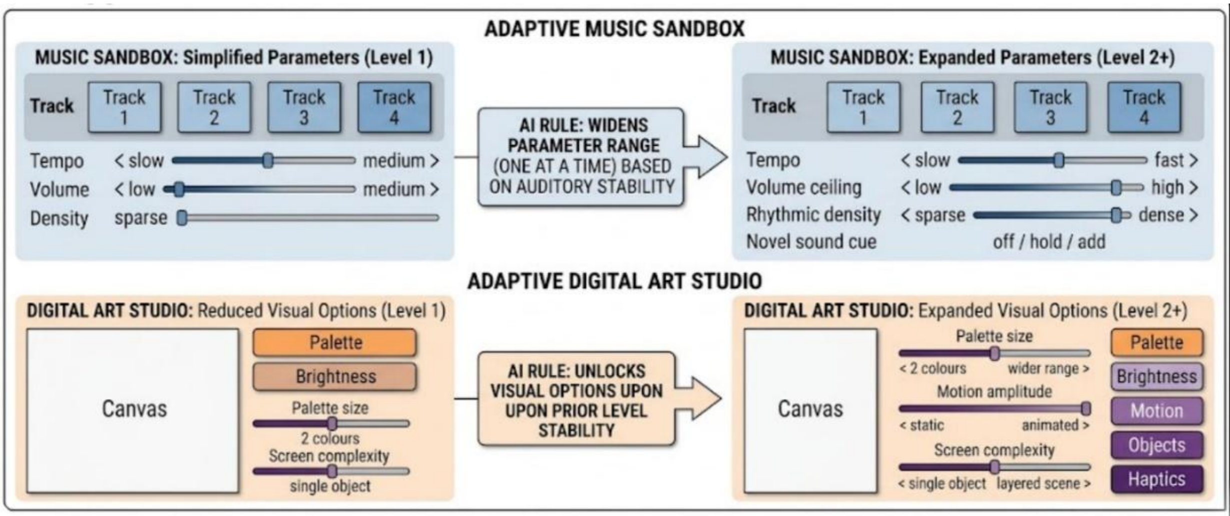

Figure 4. Functional Wireframe for the Music Sandbox and Digital Art Studio

Table 5 converts the creative-media controls into example prototype parameter bands for the Music Sandbox and Digital Art Studio, including indicative decibel bands and bounded colour palettes for low- to high-complexity use.

Table 5. Creative Module parameters for the music sandbox and digital art studio

Module	Parameter	Prototype Band / Range	Design Purpose
Music Sandbox	Master volume	45–50 dB (baseline); 50–58 dB (moderate); 58–65 dB (stretch)	Keeps audio progression gradual and inspectable
Music Sandbox	Tempo / density	60–72 BPM with 1 track; 72–88 BPM with 2–3 tracks; 88–100 BPM with bounded layering	Widens rhythmic complexity one variable at a time
Music Sandbox	Novel sound-cue timing	Introduce one new cue, then hold 20–30 s before further change	Allows a processing window before withdrawal
Digital Art Studio	Starter calming palette	#A8DADC; #F1FAEE; #BDE0FE; #CDEAC0	Supports low-saturation entry-level composition
Digital Art Studio	Expanded palette	#457B9D; #F4A261; #E9C46A; #E76F51; #6D597A; #84A59D	Adds contrast and expressive breadth after stability
Digital Art Studio	Motion / scene complexity	Static 1–2 objects; low motion 3–4 objects; moderate motion 4–6 objects with optional haptics	Controls visual load and multimodal intensity

Ethical and Privacy Considerations

The implementation of AI-based interventions raises ethical questions around privacy, interpretive accuracy, autonomy, and informed consent (Johnson & Picard, 2017). For that reason, the framework assumes encrypted data handling, minimal-data principles, caregiver control over optional sensing, and a design stance that supports the child rather than pathologizing difference.

Table 6 consolidates the design principles and shows how they are operationalized within the platform.

Table 6. Key design principles aligned with platform features

Design Principle	Implementation	Rationale
Personalization/Adaptation	Interpretable state-based AI adjusts noise, visuals, and task difficulty in real time	Addresses heterogeneous sensory & cognitive needs
Sensory Customization	User-set brightness, sound, cue timing, and complexity levels	Avoids overload while encouraging exploration
Structured Flexibility	Predictable frameworks + optional paths	Balances routine with incremental novelty
Positive Reinforcement	Immediate feedback & hidden rewards	Encourages stepping out of comfort zones
Collaboration	Caregiver dashboard, data logs	Ensures alignment with real-world objectives
Ethical Safeguards	Data encryption & consent-based sensor tracking	Respects privacy and autonomy

The principles guide the platform to use advanced technology while keeping its focus on children and maintaining ethical standards. The following section evaluates the unique aspects of this design and its potential effects on autism interventions.

Novelty and Potential Impact

This section explains how the proposed platform differs from narrower autism-support technologies and why its integrated creative-media architecture may be valuable for future prototype development and evaluation.

Novel Integration of AR, VR, and AI

Current autism-support technologies often focus on a single modality at a time, such as AR, VR, or generic AI-based performance analytics (Chung & Chen, 2017). By contrast, the present framework deliberately links AR, VR, interactive storytelling, creative-media exploration, and interpretable adaptation logic into one progression model. This is the manuscript's main conceptual novelty rather than a claim of completed system validation.

Emphasis on Comfort Zone Expansion

Research shows that most interventions teach individual abilities such as emotion recognition and language acquisition, but few programs focus on developing comfort zone expansion as a core ability (Resnick & Silverman, 2005). The technique recognizes comfort zone rigidity causes various developmental barriers which lead to both restricted peer contact and limited recreational activities (Parsons & Cobb, 2011). The platform systemically presents children to new experiences within story-based safe environments which solves a fundamental problem that affects their quality of life (Norouzi et al., 2024).

Personalization at Scale

The platform's AI engine gathers information across various activities which include AR, VR, music, and art to build an evolving user profile. Through time the AI system develops skills to set proper stimulus timing and measure challenge pacing and discover which incentives drive individual children best (Xing, 2024). The intelligent personalization approach delivers benefits to each individual user while generating new research possibilities for therapists and scientists who analyze aggregated anonymized data to develop improved strategies for autism profiles (Lydia et al., 2023).

Real-World Skill Transfer

Most VR or AR solutions fail to integrate properly with real-life practice which presents a major limitation. The platform enables real-world missions which connect to student progress in its game-like setting (Bai et al., 2015). Parents and therapists can observe how children successfully transfer skills learned in digital simulations to everyday situations through observations of skill generalization (Mubin et al., 2020).

Wider Applicability

The platform's design for autistic children can be modified to serve other people who avoid situations because of anxiety and sensory difficulties and also social anxiety patients and people with phobias (Cañete & Peralta, 2023). Its framework of incremental exposure, adaptive difficulty, and narrative engagement holds promise for broader therapeutic or educational uses.

The combination of AR, VR and AI through a unified narrative structure creates a new method to handle comfort zone limitations which form the core challenge. The following section presents thoughts about transitioning from concept to practice by discussing implementation specifics and study constraints alongside potential research possibilities.

Practical Implementation

Implementation should proceed through interdisciplinary collaboration among computer scientists, autism specialists, educators, designers, and families. Pilot deployment should begin with low-risk, culturally localized modules, especially the AR familiar-space layer and the creative-media tools, before moving toward more immersive and adaptive components. This phased approach is consistent with the framework's core logic: support should remain structured, transparent, and responsive at every stage of expansion beyond the child's existing comfort zone.

Conclusion

This manuscript has presented a conceptual framework, rather than an efficacy study, for an AI-driven, multi-modal platform designed to support the gradual expansion of autistic children's comfort zones. By linking interactive storytelling, AR in familiar spaces, VR social rehearsal, interpretable state-based AI scaffolding, creative exploration, and caregiver-supported real-world transfer, the paper clarifies how the proposed system is intended to function as a coherent developmental pathway rather than a collection of disconnected features.

Key Contributions

The manuscript makes three main contributions. First, it clarifies the purpose and methodological position of the work as a design-science-informed conceptual paper supported by literature synthesis and preliminary stakeholder research. Second, it presents an integrated framework in which the relationships among narrative structure, AR, VR, adaptive AI, sensory customization, creative-media modules, and real-world transfer are explicitly articulated. Third, it incorporates preliminary stakeholder data from Saudi Arabia to localize the framework in culturally meaningful ways, especially around family gatherings, discreet caregiver support, and sensory processing windows for unfamiliar sound.

Limitations and Future Directions

The proposed framework remains conceptual and requires empirical development in future work. The paper includes preliminary stakeholder evidence and low-fidelity exploratory materials, but it does not report a full prototype evaluation, algorithm training study, or intervention trial. Next steps should therefore include prototype construction, usability studies with caregivers and practitioners, and later-stage evaluation of acceptability, safety, and transfer into everyday settings. Future research should also explore age-specific adaptations, cost-conscious hardware pathways, and clinician-facing mechanisms for reviewing or overriding AI recommendations when required.

Overall, the revised manuscript argues that comfort-zone expansion is best approached through a staged, adaptive, and context-sensitive system that connects digital rehearsal with meaningful daily participation. The framework is offered as a foundation for future prototyping and empirical testing, not as a claim of proven clinical effectiveness.

By making the manuscript's purpose, methodology, conceptual links, ZPD-based scaffolding logic, creative-media parameters, and preliminary evidence more explicit, the paper is repositioned more clearly as a coherent conceptual contribution to research on autism support, immersive technologies, and user-centered design.

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