Original scientific paper

Towards Digital Therapeutics: Developing an Immersive Serious Game for Social Anxiety Disorder

Timothy John Pattiasina, Harits Ar Rosyid, Anik Nur Handayani, Hartarto Junaedi, Edwin Meinardi Trianto, and Raymond Sutjiadi

***Abstract* — This paper presents the engineering design and usability validation of SAVIRE (Social Anxiety–Virtual Reality–Serious Game), an immersive digital therapeutic platform for adolescents with Social Anxiety Disorder (SAD). Adopting an engineering-centered approach, SAVIRE is developed using a modular system architecture that incorporates a Behavioral Scoring Engine for real-time classification of user responses during virtual social interactions. The system is implemented using Unity 3D and the Oculus SDK and optimized for the Meta Quest 3S, leveraging inside-out tracking to enable high-fidelity immersion without reliance on external computing devices. Following the Rapid Game Development (RGD) methodology, clinically grounded therapeutic principles are translated into interactive mechanics and graded virtual exposure scenarios. Technical evaluation conducted by clinical experts using the User Experience Questionnaire (UEQ) demonstrated positive results, with mean scores exceeding 2.67 across all dimensions, including efficiency and stimulation. Usability testing involving 20 adolescents diagnosed with SAD yielded an average System Usability Scale (SUS) score of 80.38, indicating excellent usability. These findings position SAVIRE as an engineering-oriented framework for adaptive virtual simulations, contributing to the development of scalable digital therapeutic systems in mental healthcare.**

***Keywords* — Healthcare Engineering, Modular System Architecture, Serious Game, Social Anxiety, System Usability, Virtual Reality.**

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I. Introduction

The evolution of digital healthcare engineering has significantly transformed the landscape of psychological interventions, particularly for adolescent populations. In the era of ubiquitous computing, the development of immersive therapeutic platforms presents a promising pathway for addressing complex mental health challenges. Social Anxiety Disorder (SAD) is one of the most common anxiety conditions in adolescence, affecting social development, academic achievement, and future career opportunities [1]. Adolescents are especially vulnerable to SAD, as this developmental stage plays a critical role in the formation of social identity, emotional regulation, and self-esteem [2].

Despite the demonstrated effectiveness of established treatment approaches such as Cognitive Behavioral Therapy (CBT) [3], [4] and pharmacological interventions [5], access to these treatments remains constrained by practical barriers, including limited availability of trained therapists, high treatment costs, and persistent stigma surrounding mental health care [6]. In addition, conventional therapeutic formats often rely on repetitive verbal exercises and passive engagement, which may reduce motivation and treatment adherence among adolescents [7]. These limitations have motivated the exploration of technology-driven solutions capable of delivering engaging, scalable, and user-centered therapeutic experiences.

Advances in digital mental health systems have positioned Virtual Reality Exposure Therapy (VRET) as a promising modality for the treatment of anxiety-related disorders [8]. Grounded in CBT principles, VRET enables users to confront anxiety-provoking situations within safe and controllable virtual environments, supporting gradual exposure, emotional regulation, and social skill rehearsal. However, standalone VR exposure systems may offer limited engagement over extended use. Integrating Serious Game (SG) into VR environments introduces structured challenges, adaptive feedback mechanisms, and reward-based progression, thereby enhancing user motivation and facilitating sustained interaction and learning.

In this context, the present study introduces SAVIRE (Social Anxiety–Virtual Reality–Serious Game), an immersive Virtual Reality Serious Game (VRSG) prototype designed for adolescents with SAD [9], [10]. Developed using Unity 3D and VR-compatible hardware, SAVIRE translates clinically grounded principles from CBT, Social Learning Theory (SLT), and Revised Bloom's Taxonomy into interactive game mechanics and graded virtual scenarios. Employing a Rapid Game Development methodology, the system emphasizes modular design, usability, and iterative refinement through expert evaluation and adolescent user testing. By explicitly addressing both therapeutic objectives and engineering implementation, this work contributes an engineering-oriented foundation for scalable and adaptive digital therapeutic systems within the broader domain of mental health interventions.

The novelty of this work lies in the operationalization of therapeutic theories into an event-driven virtual reality system architecture, where—unlike prior VR-based serious game for social anxiety that primarily emphasize therapeutic outcomes [11]-[13], behavioral constructs in SAVIRE directly govern interaction logic, adaptive scoring, and scenario progression.

II. Methodology and System Design

A. *Design Framework*

The development of the SAVIRE system adopts an engineering-oriented design framework that systematically translates clinical and educational theories into implementable virtual reality system components. Rather than positioning therapeutic theories as abstract design references, this study operationalizes them as functional drivers that directly influence system architecture, interaction logic, and scenario progression. The overall framework employed in this work is illustrated in Fig. 1.

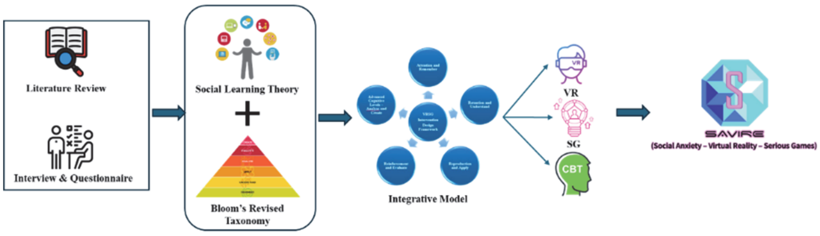

Fig. 1. Conceptual Engineering Framework of the SAVIRE System.

As shown in Fig. 1, Social Learning Theory (SLT) forms the behavioral foundation of the system by guiding how users observe, practice, and reinforce social behaviors within the virtual environment. These principles are implemented through non-player character (NPC) modeling, interactive task sequences, and reinforcement mechanisms that provide immediate system feedback. From an engineering perspective, SLT informs the design of behavioral loops that ensure repeatability, consistency, and measurable user interaction outcomes across sessions.

To structure cognitive engagement and task complexity, SLT is integrated with Bloom's Revised Taxonomy. This integration enables the hierarchical organization of virtual scenarios based on cognitive demand, ranging from basic recognition of social cues to higher-order decision-making and self-reflection. Within the system logic, this taxonomy governs the sequencing of tasks, escalation of environmental stressors, and interaction density, allowing controlled progression that can be systematically adjusted and evaluated.

Cognitive Behavioral Therapy (CBT) principles are embedded as functional control mechanisms within the system. These principles regulate exposure sequencing, emotional self-assessment, and feedback delivery during gameplay. In the SAVIRE framework, CBT is implemented through rule-based exposure levels, in-game anxiety rating inputs, and adaptive feedback modules. By integrating SLT, Bloom's Taxonomy, and CBT into a unified engineering framework, SAVIRE establishes a reproducible design model that bridges therapeutic objectives with system-level implementation requirements.

B. *Prototype Development*

The SAVIRE prototype was developed using the Rapid Game Development (RGD) methodology, which emphasizes iterative implementation, early validation, and continuous refinement [14]. This methodology was selected due to its suitability for interactive systems that require close alignment between functional performance, user experience, and domain-specific requirements such as digital therapeutics.

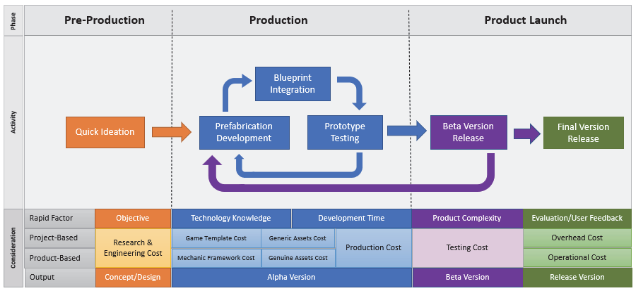

Fig. 2. Three-Phase RGD Pipeline for Therapeutic System Design.

The RGD process in this study consists of three main stages: Pre-Production, Production, and Product Launch (Fig. 2). During the Pre-Production stage, system requirements were defined through interdisciplinary collaboration between developers and mental health professionals. At this stage, therapeutic objectives were translated into technical specifications, including interaction flow diagrams, exposure level definitions, and scenario logic. Design artifacts such as wireframes, storyboards, and interaction schemas were produced to serve as engineering references for system implementation.

The Production stage focuses on transforming design specifications into a functional VR system. SAVIRE is implemented using the Unity 3D engine, which provides modular architecture, real-time rendering, and native support for virtual reality development. Core system components include scenario controllers, NPC behavior modules, navigation and interaction handlers, and feedback

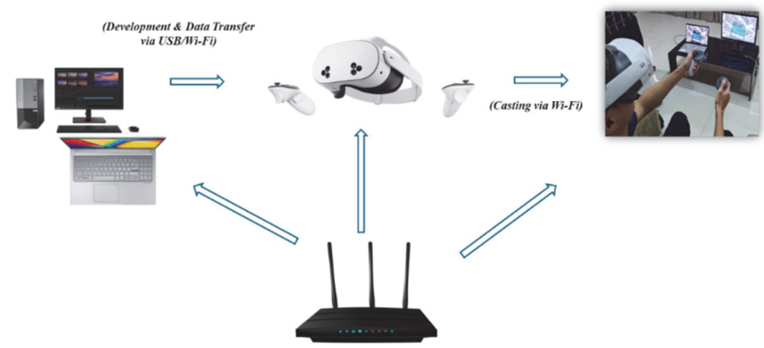

Fig. 3. System Architecture and Deployment Flow of the SAVIRE Standalone VR Prototype.

management systems. The prototype is optimized for the Meta Quest 3S headset using the Oculus SDK, enabling untethered operation through inside-out tracking while maintaining stable performance and minimizing motion-related discomfort.

The deployment architecture of the SAVIRE prototype is illustrated in Fig. 3. The system is implemented as a standalone VR application, where development and testing are conducted on a workstation using Unity 3D, while runtime execution occurs entirely on the VR headset. User interactions are processed locally through event-driven modules, enabling real-time feedback without dependency on external computing resources.

At the time of this study, SAVIRE remains in the Production stage, where iterative refinements are driven by expert feedback and preliminary user observations. Ongoing development efforts focus on improving interaction responsiveness, NPC behavior consistency, and system feedback clarity. The forthcoming Product Launch stage will include extended usability testing, performance optimization, and the implementation of data management and security mechanisms to support broader deployment and future clinical studies.

C. *Evaluation Strategy and Participant Involvement*

The evaluation of the SAVIRE system follows a two-layer assessment strategy designed to capture both expert-level validation and end-user usability [15]. This approach aligns with engineering evaluation practices by combining system inspection from domain specialists with empirical usability testing involving target users.

During the initial evaluation phase, the prototype was assessed using the User Experience Questionnaire (UEQ) by three mental health professionals, including two licensed psychologists and one therapist with experience in treating adolescent Social Anxiety Disorder (SAD). The UEQ evaluates six dimensions: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty [16]. From an engineering perspective, these dimensions provide structured indicators of interface clarity, interaction efficiency, and overall system quality. The mean score for each UEQ dimension was computed as:

$$S_d = \frac{\sum_{i=1}^{N} R_{i,d}}{N} \tag{1}$$

where S_d represents the average score for dimension d, $R_{i,d}$ denotes the response score provided by evaluator i, and N is the total number of evaluators. An overall UEQ score was obtained by aggregating the mean values across all evaluated dimensions.

The second evaluation layer involved usability testing with 20 adolescents clinically diagnosed with SAD. Participants were recruited through local mental health clinics, with eligibility confirmed by professional assessment. Ethical considerations were addressed through informed consent, anonymity of participant data, and the exclusion of individuals with conditions that could pose safety risks during VR interaction. After engaging with the SAVIRE prototype, participants completed the System Usability Scale (SUS), a standardized instrument for measuring perceived usability in interactive systems [17]. The final SUS score was calculated using the standard normalization formula:

$$SUS = \left(\sum_{i=1}^{N} S_i\right) \times 2.5 \tag{2}$$

where S_i denotes the adjusted score of each SUS item following standard SUS guidelines.

By combining expert-based UEQ evaluation with user-centered SUS testing, this study obtains complementary insights into both system design quality and practical usability. This mixed evaluation strategy supports iterative system refinement and provides an engineering-oriented validation of SAVIRE as an immersive virtual reality serious game for digital mental health applications.

III. Prototype Development of SAVIRE

The development of SAVIRE (Social Anxiety–Virtual Reality–Serious Game) follows the Rapid Game Development (RGD) methodology, emphasizing iterative prototyping, continuous expert feedback, and progressive system refinement. The development lifecycle is structured into five phases: planning, pre-production, production, testing, and deployment. At the time of this study, SAVIRE is in the production phase, where core system modules—including environment logic, non-player character (NPC) behaviors, and interaction mechanics—have been implemented and are undergoing iterative refinement based on expert and user feedback.

A. *SAVIRE Environment and Therapy-Oriented System Design*

The SAVIRE prototype implements a previously defined VRSG engineering framework (Fig. 1), translating therapeutic objectives into modular system components. The primary virtual environment is a supermarket scenario, selected due to its high ecological validity as a socially demanding yet controllable setting for individuals with Social Anxiety Disorder (SAD). From an engineering perspective, the supermarket environment enables structured manipulation of social density, interaction frequency, and environmental stressors.

The environment incorporates multiple configurable parameters, including NPC population density, navigation constraints, and ambient audio intensity. Users interact with dynamic NPCs exhibiting context-aware behaviors such as path obstruction, queue formation, and verbal engagement at checkout points. These elements are designed to simulate real-world social pressure while maintaining a controlled exposure framework. Immersion is further supported through spatial audio cues, visual navigation aids, and guided interaction prompts, enabling users to engage with the environment at a manageable pace.

Scenario complexity is progressively increased through system-controlled parameters, allowing exposure intensity to adapt based on task completion and user interaction flow [18]. This adaptive design supports emotional regulation training and ensures that therapeutic exposure remains incremental and measurable.

B. Clinically Informed Scenario and Interaction Design

Scenario design in SAVIRE was conducted through close collaboration with two licensed psychologists and one experienced therapist to ensure clinical validity and alignment with established therapeutic practices. Their contributions informed the selection of social interaction types, escalation patterns, and decision-making challenges embedded within the virtual environment.

The prototype is structured into three sequential stages, each representing an increasing level of social and cognitive demand:

- Stage 1: Guided Environment Exploration

Users navigate the supermarket using system-generated waypoints while adapting to baseline stressors such as crowd density, NPC movement, and ambient noise. Emotional self-assessment is performed at predefined checkpoints to capture perceived anxiety levels and user adaptation trends (Fig. 4).

Fig. 4. Navigation & Checkpoint Exploration.

- Stage 2: Item Search with Social Interference

Users are tasked with locating specific items while encountering socially challenging NPC behaviors, including blocked shelves, group formations, and disruptive actions. Users may choose avoidance, passive waiting, or assertive engagement strategies, each influencing behavioral scoring metrics related to coping and social response effectiveness (Fig. 5).

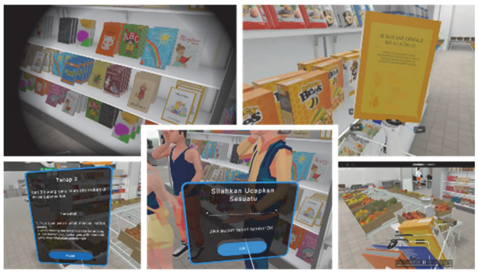
Fig. 5. Searching for Items and Facing Social Challenges.

- Stage 3: Checkout Interaction and Exit Simulation

The final stage simulates high-pressure social interactions such as queuing, interruptions, and confrontational exchanges. Users respond using predefined interaction options reflecting assertive, neutral, or passive communication styles. Upon completion, the system provides a summary of task performance and anxiety self-rates (Fig. 6).

Fig. 6. Exit Simulation after Checkout and Payment.

Across all stages, scenario progression reflects key principles of Social Learning Theory—attention, retention, reproduction, and reinforcement—while operationalizing CBT techniques such as exposure control, emotional recognition, and behavioral reframing through interactive system logic.

C. Core Prototype Features and Technical Limitations

The current SAVIRE prototype integrates several core features designed to simulate real-world social encounters within a controlled virtual environment. These include a fully navigable supermarket scene, dynamic NPC behavior models, progressive task sequencing, guided navigation support, and system-based anxiety self-report mechanisms coupled with behavioral scoring (Fig. 7).

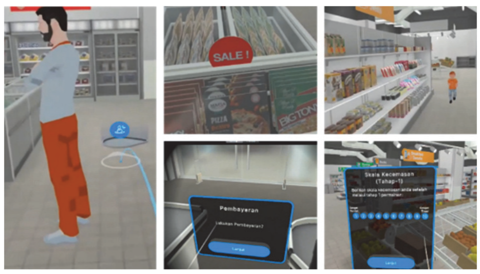

Fig. 7. SAVIRE Prototype: Navigation, NPCs, and Tasks.

From an engineering standpoint, the prototype adopts a modular design architecture, enabling individual components—such as NPC behavior logic, scenario controllers, and feedback mechanisms—to be independently refined and extended. While essential mechanics including navigation, NPC interaction, and scenario flow are fully implemented, advanced interaction modules—such as adaptive response selection and real-time behavioral adaptation—remain under active development.

Future iterations will focus on enhancing NPC responsiveness, expanding interaction variability, and integrating physiological sensing technologies (e.g., heart rate monitoring) to support objective anxiety detection and adaptive feedback [19]. These enhancements aim to strengthen personalization capabilities and position SAVIRE as a scalable, engineering-driven virtual reality therapeutic system for adolescent social anxiety intervention.

IV. Results and Evaluation

The SAVIRE prototype was evaluated using a two-stage assessment strategy consisting of expert-based user experience evaluation and usability testing with adolescent end users. This section reports the evaluation results and discusses their implications from an engineering and system design perspective.

A. Expert UEQ Evaluation

An expert-based evaluation was conducted involving three mental health professionals, two psychologists (P1, P2) and one counselor (C) with experience in adolescent Social Anxiety Disorder (SAD) therapy (Fig. 8). The expert evaluation was conducted in a supervised setting using standalone VR hardware. Each expert interacted with the SAVIRE prototype and completed the User Experience Questionnaire (UEQ), which measures six dimensions: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty.

The average UEQ dimension scores (Table 1) ranged from 2.67 to 2.83, indicating a consistently positive expert assessment of the system's user experience. The aggregated UEQ score of 2.75 suggests that SAVIRE is perceived as usable, engaging, and aligned with its intended therapeutic objectives. High scores in perspicuity and stimulation (both 2.83) indicate that the interaction flow is easy to understand and provides sufficient engagement. In contrast, slightly lower scores in dependability and novelty (both 2.67) highlight opportunities for improving system consistency and increasing interaction variability in future iterations.

Table 1: Average UEQ Scores for SAVIRE

UEQ Dimension	Mean Score
Attractiveness (A)	2.72
Perspicuity (P)	2.83
Efficiency (E)	2.75
Dependability (D)	2.67
Stimulation (S)	2.83
Novelty (N)	2.67

Internal consistency analysis yielded a Cronbach's Alpha value of 0.712, which indicates acceptable reliability for expert-based evaluation. From an engineering perspective, these results highlight that the core system architecture and interaction logic are functional, while further refinement is required to enhance robustness and introduce additional adaptive interaction elements.

B. SUS Evaluation of SAVIRE Prototype

Usability testing was conducted with 20 adolescents clinically diagnosed with Social Anxiety Disorder to assess SAVIRE's ease of use and interaction quality. Participants completed a System Usability Scale (SUS) questionnaire after interacting with the prototype.

The SUS evaluation resulted in a mean score of 80.38, with scores ranging from 62.5 to 92.5 (Table 2), indicating consistently high perceived usability among participants, according to standard SUS interpretation guidelines. This result suggests that the system interface, navigation flow, and interaction mechanics are accessible and acceptable for adolescent users, supporting SAVIRE's suitability as a self-guided virtual reality intervention.

Table 2: SUS Summary statistics for SAVIRE.

Metric	Value
Number of participants	20
Mean SUS score	80.38
Minimum SUS score	62.5
Maximum SUS score	92.5

Beyond quantitative usability scores, participants provided qualitative feedback related to immersion quality, NPC realism, and interaction clarity. These insights informed engineering-level refinements, particularly in NPC behavior consistency, response timing, and navigation feedback mechanisms.

C. Engineering Implications and System Validation

In addition to usability outcomes, the evaluation results validate the underlying engineering design of SAVIRE, particularly its modular and event-driven system architecture. User interactions within the virtual environment are processed through an interaction evaluation layer that determines adaptive or non-adaptive responses, which subsequently trigger decoupled system events responsible for updating behavioral scores, interaction states, and scenario progression without introducing direct dependencies between gameplay components.

This adaptive mechanism enables flexible system refinement and supports scalable development. As illustrated in Figure 9, user interaction outcomes are first evaluated and dispatched through a centralized event mechanism, after which independent modules—namely phase-based scoring, obstacle state management, and interaction enablement—are activated in parallel. This separation of concerns ensures that modifications to scoring logic or interaction flow can be implemented without altering core gameplay mechanics.

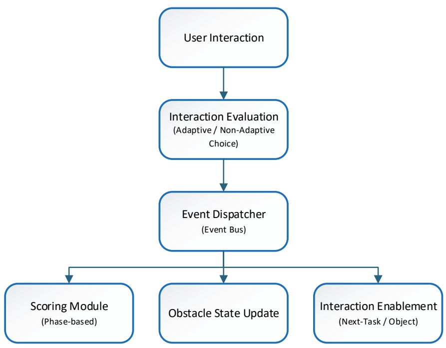

Fig. 9. Simplified Event-driven Scoring & Mechanism.

From an engineering perspective, the event-driven architecture of SAVIRE enables adaptive behavioral evaluation and immersive feedback while decoupling system logic from interaction flow, consistent with findings on diegetic interface design in immersive games [20]. This demonstrates that the reported usability results are directly linked to concrete system design decisions and future refinement strategies.

V. Conclusions

This study presents SAVIRE, an immersive virtual reality serious game developed as a digital therapeutic prototype for adolescents with Social Anxiety Disorder (SAD). By translating principles from Cognitive Behavioral Therapy (CBT), Social Learning Theory (SLT), and Revised Bloom's Taxonomy into modular, event-driven engineering architecture, SAVIRE demonstrates how clinically grounded concepts can be systematically operationalized within an interactive VR environment using Unity 3D and standalone VR hardware. Evaluation involving mental health experts and adolescent users indicates a positive user experience and excellent usability, as reflected by UEQ scores across all dimensions and an average SUS score of 80.38. Beyond reporting usability metrics, the results validate the underlying system design by linking evaluation outcomes to concrete engineering implications, particularly through the adaptive scoring and state management mechanism that supports flexible refinement and scalability. Future work will focus on enhancing interactive mechanics, integrating adaptive feedback, and conducting broader evaluations using standardized clinical measures and comparison groups to further assess therapeutic effectiveness. Overall, this work contributes an engineering-oriented foundation for the development of scalable, user-centered virtual reality–based digital therapeutics for social anxiety intervention.

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