Title	AI-guided self-training in virtual reality for social anxiety disorder (SAD)
Sub Title	
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Publisher	慶應義塾大学大学院システムデザイン・マネジメント研究科
Publication year	2025
Jtitle	
JaLC DOI	
Abstract	
Notes	修士学位論文. 2025年度システムデザイン・マネジメント学 第584号
Genre	Thesis or Dissertation
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO40002001-00002025-0009

Master's Dissertation 2025

AI-Guided Self-Training in Virtual Reality for Social Anxiety Disorder (SAD)

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September 2025

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SUMMARY OF MASTER'S DISSERTATION

Student Identification Number	82334597	Name	Kongjia Li

Title

AI-Guided Self-Training in Virtual Reality for Social Anxiety Disorder (SAD)

This study focuses on the development of a self-training system that leverages virtual reality (VR) and artificial intelligence (AI) to support individuals with Social Anxiety Disorder (SAD). The researcher identified limitations in existing interventions, such as the lack of interactivity, immersion, and structured guidance, and proposed a multi-modal approach that combines immersive scenarios with reflective dialogue. The research began by defining the goals of the intervention, identifying user needs, and designing a system architecture based on the Inquiry-Based Stress Reduction (IBSR) method. The system integrates an AI dialogue agent with a VR environment that simulates mild social situations. Four experimental conditions were implemented: AI-only, VR-only, AI+VR, and a traditional human-guided IBSR session. After conducting the experiment and collecting pre- and post-intervention anxiety scores using the SIAS scale, the researcher compared the effects across groups. The results showed that the AI+VR condition produced improvements comparable to the traditional IBSR group, indicating the potential of scalable and privacy-preserving digital tools for mental health support. Future research will explore adaptive dialogue, emotion-aware systems, and multi-session training formats.

Keywords (5 words)
Virtual Reality, Social Anxiety, AI Dialogue, IBSR, Self-Training

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Chapter 1 Introduction

1.1 Research Background and Motivation

Social Anxiety Disorder (SAD) is the third most common mental health condition globally, affecting approximately 5–10% of the population [1]. It is a chronic and pervasive disorder characterized by an overwhelming fear of being judged, rejected, or embarrassed in social or performance situations. Individuals with SAD often experience intense anxiety when speaking in public, meeting new people, or even engaging in casual interactions. Common symptoms include avoidance of eye contact, silence in group settings, and withdrawal from social activities. These behaviors can severely impair daily functioning, academic or occupational performance, and overall quality of life.

According to a nationally representative epidemiological study from India, individuals aged 18 to 29 comprise the largest proportion of current SAD cases, accounting for 40.8% of all diagnosed individuals, as shown in Figure 1 [1]. This age group represents a crucial developmental period for forming identity, building relationships, and exploring career paths. Without timely support, young adults in this

stage may face long-term challenges such as low self-esteem, academic underachievement, and increased vulnerability to depression.

	Sample *n* (%)	Social anxiety disorder *n* (%)
Total	34802	125
Age group^		
18 to 29	11848 (34)	51 (40.8)
30 to 39	7062 (20.3)	30 (24.0)
40 to 49	5854 (16.8)	16 (12.8)
50 to 59	4448 (12.8)	17 (13.6)
60 and above	5590 (16.1)	11 (8.8)

Figure 1 Comparison of sample characteristics between total sample and persons with social anxiety disorder [1]

1.2 Problem Statement

Although traditional interventions such as Cognitive Behavioral Therapy (CBT) have been proven effective for treating social anxiety, prior studies indicate that these treatments are not truly accessible to many young people [2]. Accessibility, in this context, goes beyond the mere availability of clinical methods—it includes whether individuals are willing, able, and comfortable enough to engage with them.

For young individuals with early signs of social anxiety, several barriers often prevent them from seeking help. These include fear of being judged, long waiting times for appointments, the high cost of therapy, and difficulty engaging in self-reflection

without human support. Together, these factors create a psychological and logistical gap that makes it difficult for at-risk youth to benefit from existing interventions.

This gap highlights the urgent need for a new form of support—one that is self-directed, emotionally approachable, and free from the stigma or pressure often associated with traditional therapy settings.

In response to this need, this study proposes an innovative solution: a self-guided training platform that integrates immersive VR environments with AI-driven dialogue to enhance both emotional engagement and cognitive restructuring for individuals with emerging social anxiety symptoms.

1.3 Research Objectives and Contributions

This study aims to develop and evaluate a self-guided digital intervention that integrates Virtual Reality (VR), Artificial Intelligence (AI), and the Inquiry-Based Stress Reduction (IBSR) method to support young individuals who have not received a clinical diagnosis but exhibit early signs of social anxiety. IBSR is a structured cognitive approach designed to help individuals identify and reframe stressful beliefs through a series of guided questions and turnaround thinking.

Unlike traditional VR-based exposure therapies that simulate realistic social situations, the VR component in this system does not recreate specific external scenarios. Instead, it presents immersive, visually rich environments that correspond to each cognitive stage of the IBSR process—helping users emotionally connect with and reflect on their thoughts during self-inquiry. At the same time, the AI component delivers personalized, adaptive dialogue that guides users through the full IBSR questioning framework, allowing for deep cognitive exploration without the need for a human facilitator.

The overarching goal of this research is to improve psychological accessibility for individuals who are hesitant or unable to seek conventional therapy due to fear of judgment, long waiting times, high treatment costs, or difficulty initiating self-reflection without guidance. By combining immersive emotional contexts with real-time cognitive support in a private and self-paced format, the proposed system aims to offer a scalable and approachable alternative to early-stage intervention.

To evaluate its effectiveness, the study includes four experimental groups: AI-only, VR-only, the combined AI+VR system (the proposed solution), and traditional therapist-led IBSR. All groups follow the same IBSR structure but differ in delivery modality. Pre- and post-intervention scores on the Social Interaction Anxiety Scale (SIAS) are used to assess changes in anxiety symptoms across conditions.

The desired outcome is that the AI+VR system will outperform the single-modality groups (AI-only and VR-only) and approximate the effectiveness of human-facilitated IBSR. This would demonstrate the potential of AI+VR as a viable, therapist-free intervention that maintains both therapeutic impact and user autonomy—particularly for non-clinical young adults seeking accessible support.

1.4 Structure of the Thesis

This thesis is structured into six chapters, each building upon the previous to explore the integration of AI and VR technologies within the framework of Inquiry-Based Stress Reduction (IBSR) for alleviating social anxiety. Chapter 1 introduces the research background and motivation, defines the core problem statement, outlines the research objectives, and explains the overall organization of the thesis.

Chapter 2 provides a comprehensive literature review covering the theoretical foundations and empirical studies related to Social Anxiety Disorder (SAD), the use of virtual reality (VR) in mental health interventions, AI-based dialogue systems for psychological support, and the principles of the IBSR method. It also explores recent developments in multi-modal intervention systems and identifies the key research gaps that this study aims to address.

Chapter 3 presents the methodology and system design. It outlines the research framework and proposed hypotheses, describes the structure of the four experimental groups, and details the participant recruitment criteria and ethical considerations. Furthermore, it explains the measurement tools used, such as the Social Interaction Anxiety Scale (SIAS), and elaborates on the technical architecture, including the training of the AI dialogue agent and the design of IBSR-based VR scenes within a Unity environment.

Chapter 4 reports the experimental procedures and data analysis. It includes an overview of participant demographics, followed by quantitative results based on pre- and post-intervention SIAS scores, paired t-tests, ANOVA, and effect size calculations. The chapter also presents qualitative insights, including behavioral feedback and system usability observations.

Chapter 5 discusses the key findings in light of existing literature, examines the theoretical and practical implications of integrating AI and VR in cognitive interventions, and reflects on the limitations of the current study. It offers suggestions for future work, such as improving the personalization of AI responses, expanding sample diversity, and exploring longitudinal therapeutic effects.

Finally, Chapter 6 concludes the thesis by summarizing the study's contributions, restating the research goals, and emphasizing the potential of combining immersive technology and cognitive inquiry for advancing digital mental health solutions.

Chapter 2 Literature Review

2.1 Social Anxiety Disorder and Its Cognitive Basis

Building upon the foundational understanding of SAD introduced earlier, this section further explores cognitive models and the mechanisms that sustain these symptoms, such as negative self-imagery, safety behaviors, and biased information processing. [3].

Despite the significant impact of these symptoms, many young people do not seek treatment due to stigma, time constraints, financial barriers, or a desire for privacy.

Cognitively, SAD is not simply shyness or introversion, but a disorder rooted in deeply held beliefs about one's social inadequacy and fear of negative evaluation. Individuals with SAD commonly interpret ambiguous social cues—such as silence or neutral expressions—as signs of disapproval and maintain intense self-monitoring during interactions [4]. This leads to an overestimation of their own anxiety symptoms

(e.g., blushing, shaking) and results in safety behaviors such as avoiding eye contact, staying silent, or rehearsing speech, which prevent disconfirmation of their fears and reinforce avoidance cycles [5][6].

Early social experiences play a critical role in the development of SAD. Negative parenting styles (e.g., overly critical or overprotective) and adverse peer experiences, such as bullying or exclusion, can heighten sensitivity to social threats [7]. This is especially impactful for younger individuals, whose social identities are still forming. These experiences contribute to maladaptive social schemas and a persistent expectation of rejection.

In recent years, Virtual Reality (VR) has emerged as a promising tool for delivering mental health interventions to young people, particularly because of its immersive, controlled, and private nature. Young digital natives often prefer technology-based tools over traditional therapy [2]. However, most existing VR interventions focus solely on exposure to feared scenarios and fail to incorporate structured cognitive restructuring, limiting their long-term effectiveness [2].

2.1.1 Cognitive Interventions: CBT vs. IBSR

Cognitive Behavioral Therapy (CBT) is the most established intervention for Social Anxiety Disorder (SAD) and has shown robust effectiveness across studies. CBT

typically involves therapist-led sessions, combining behavioral exposure with cognitive restructuring techniques to challenge irrational beliefs and reduce avoidance behavior [5][6]. However, the approach has several limitations for young users and digital delivery:

- Accessibility – CBT requires trained therapists, making it time- and cost-intensive.
- User resistance – Some individuals, particularly youth, may resist externally imposed "corrections" to their thoughts.
- Therapist dependence – The effectiveness of CBT is highly dependent on the quality of therapist interaction, which is difficult to replicate in self-guided digital systems [2].

Inquiry-Based Stress Reduction (IBSR), in contrast, offers a reflective, user-centered method of addressing negative beliefs. IBSR involves four guided self-inquiry questions that help users examine the truth, consequences, and possible alternatives of their thoughts. Instead of replacing thoughts directly, IBSR promotes self-discovery and emotional processing through experiential reflection.

This approach aligns well with young users who seek more autonomy and privacy. IBSR's introspective structure also maps naturally onto immersive VR environments, where each question can be embodied through visual metaphors and scenario transitions. Importantly, IBSR requires no external therapist input and is therefore more suitable for

scalable, AI-driven delivery.

In fact, when various psychological interventions are classified by delivery style, target group, and learning difficulty, IBSR is listed as a beginner-friendly method, along with simplified CBT models, due to its ease of implementation and low risk. It is also recommended for use with children and adolescents because of its interactive and modular design.

Category	Recommended Methods	Reason
Short-Term Effective	CBT, SFBT, IBSR, ACT	Highly structured, suitable for standardized training
Group-Oriented	MBCT, DBT, PCT, SST	Comes with structured manuals and group processes
Beginner-Friendly	IBSR, Introductory CBT Modules, Simplified SFBT	Easy to learn and apply, low risk
Children & Adolescents	SST, FST, Mindfulness Training	Highly interactive and modularizable

Figure 2 Intervention Methods by Type and Target Group

Figure 2 categorizes widely used mental health interventions according to their short-term effectiveness, group orientation, accessibility for beginners, and applicability to children and adolescents. IBSR is featured in both the “Short-Term Effective” and “Beginner-Friendly” categories, highlighting its structured yet accessible nature. This supports its suitability for standardized, self-guided digital interventions—particularly for individuals without prior therapeutic experience.

A randomized controlled trial demonstrated that applying IBSR to adults who stutter—individuals frequently experiencing social anxiety—led to significant reductions in anxiety and enhanced emotional resilience [8]. These findings suggest that

IBSR can be a viable intervention for broader anxiety-related conditions, including SAD.

2.1.2 Why This Study Uses IBSR

This research adopts IBSR over CBT for three main reasons:

1. **It supports self-guided, autonomous engagement**, eliminating the need for therapist involvement.
2. **Its structure aligns with VR scene design**, allowing the four stages of IBSR to be translated into visual, immersive sequences.
3. **It offers a more emotionally accepting and user-driven process**, which may be more appealing to young users compared to directive therapy models.

In summary, while CBT remains the gold standard in clinical settings, IBSR offers a flexible, user-driven alternative that fits the needs of young people—especially those experiencing subclinical social anxiety who are unlikely to seek traditional help. Its suitability for digital environments makes it ideal for integration into AI- and VR-based self-training systems.

2.2 The Inquiry-Based Stress Reduction (IBSR) Method

Inquiry-Based Stress Reduction (IBSR) is a structured, self-facilitated technique for addressing stress-inducing thoughts through guided reflection. Developed by Byron Katie in the 1980s and often referred to as "The Work," IBSR helps individuals recognize that emotional suffering stems not from external events, but from the beliefs attached to them. Through a meditative inquiry process, participants are encouraged to examine the veracity and consequences of their thoughts, and ultimately arrive at more balanced perspectives [11].

The IBSR process consists of four core questions, followed by a "turnaround" phase:

1. Is it true?
2. Can you absolutely know that it's true?
3. How do you react—what happens—when you believe that thought?
4. Who would you be without that thought?

Question	Format of answer
Q1: Is this thought true?	Yes vs. no
Q2: Can you absolutely know that this thought is true?	Yes vs. no
Q3: How do you react, what happens when you have this thought?	Open
Does that thought bring peace or stress to your life?	Open
What emotions arise when you have that thought?	Open
What physical sensations arise having these emotions?	Open
What images do you see, past or future, as you think this thought?	Open
How do you treat yourself when you have this thought?	Open
How do you treat others when you have this thought?	Open
Do any obsessions or addictions begin to appear when you have this thought (e.g., alcohol, drugs, shopping, food, television)?	Open

Figure 3 Inquiry-based stress reduction (IBSR) questions used in the present study [12].

The turnaround involves reversing the original belief in three ways: toward the self, the other, and the opposite. For instance, the belief "They rejected me" may become "I rejected myself," "I rejected them," or "They didn't reject me." Each reversal is followed by identifying evidence that supports the new interpretation. This fosters non-dual awareness, cognitive flexibility, and emotional resilience [11].

Unlike traditional Cognitive Behavioral Therapy (CBT), which often relies on therapist-led thought restructuring, IBSR promotes introspective, experiential transformation. CBT tends to challenge thoughts through logical disputation, while IBSR gently guides individuals to discover personal insights through self-inquiry. This emphasis on autonomy makes IBSR especially suitable for scalable, self-help applications—such as AI-assisted or virtual reality–based interventions [10].

IBSR has been shown to improve well-being in both clinical and non-clinical settings. For example, during the COVID-19 pandemic, Zadok-Gurman et al. (2021) applied a 20-week IBSR intervention with schoolteachers and observed significant increases in subjective well-being, resilience, mindfulness, and life satisfaction, along with reduced burnout and emotional exhaustion [10]. Similarly, Luff and Ledingham (2017) highlighted IBSR's value in therapeutic contexts, particularly for counselor self-care, emotional regulation, and enhancing the therapeutic alliance between practitioners and clients [11].

In educational contexts, IBSR also demonstrates strong potential. A recent study by Saputri et al. (2024) explored the use of IBSR as a psychological intervention to alleviate student stress in high school biology classes. The researchers found that students who engaged in IBSR sessions experienced significant reductions in cognitive anxiety, enhanced intrinsic motivation, and improved knowledge construction. By challenging self-limiting beliefs such as “I’m not good at science,” students became more confident and engaged in their academic tasks. This study confirms that IBSR is not only effective in reducing stress but also supports cognitive-emotional integration in learning environments [9].

Overall, IBSR offers a minimalist yet impactful pathway to psychological transformation. Its emphasis on self-reflection, non-judgment, and cognitive restructuring without confrontation positions it as a unique method distinct from traditional therapies. Because of its simplicity, versatility, and adaptability, IBSR holds particular promise in digital mental health applications—especially those requiring autonomous user engagement, such as AI-guided virtual interventions for anxiety-related disorders.

2.3 AI-Based Dialogue Systems in Psychological Support

The use of AI-based dialogue systems in psychological support has gained increasing attention due to their accessibility, scalability, and perceived neutrality. These systems—powered by natural language processing and, more recently, large language models—can simulate human-like conversations to deliver emotional support, guidance, or companionship. Their potential is particularly evident in populations experiencing mild to moderate psychological distress, especially where stigma, lack of access to services, or reluctance to seek help present barriers to conventional therapy.

One line of research has explored prompt-driven chatbot systems designed to serve as peer-like mental health companions. These systems allow users to input emotional states, daily experiences, or existential concerns, and receive tailored, context-aware responses. Studies have shown that such interactions foster temporary relief from anxiety, enhance users' self-reflection, and provide a sense of connection through language that is perceived as empathetic and responsive [13]. Notably, users often preferred these systems over static digital interventions such as self-help modules or FAQ-style applications, citing the benefits of interactivity, immediacy, and emotional resonance.

These systems also introduce a low-threshold entry point for individuals who may be hesitant to engage in face-to-face therapy. The non-judgmental nature of AI agents and the ability to engage anonymously are particularly advantageous for populations with social inhibition or shame-related barriers to help-seeking. The design choice to frame the chatbot as a “peer” rather than an “expert” further reduces perceived authority gradients, encouraging honest self-expression and exploration of distressing emotions.

Complementing this research, experimental studies have investigated how socially anxious individuals react to embodied AI counselors compared to human counselors in controlled settings. In one such study, participants with elevated social anxiety levels were found to exhibit significantly lower anticipatory anxiety when informed they would speak with a robot, as opposed to a human [14]. This pattern persisted into the interaction phase: both subjective reports and mood-state measures indicated that robotic counselors induced less tension and discomfort. These findings underscore the role of AI agents as socially “safer” interlocutors, especially for individuals sensitive to evaluation and interpersonal scrutiny.

These observations suggest that AI dialogue systems could play a meaningful role in bridging gaps in psychological service access, offering early-stage support and functioning as preparatory tools for more intensive interventions. By reducing the

emotional risk associated with interpersonal disclosure, such systems can help users engage with psychological content in a progressive and self-paced manner.

2.3.1 Limitations of Existing AI Systems: Incompatibility with IBSR

The existing AI-based dialogue systems explored in prior studies have primarily been designed to deliver general emotional support or replicate basic principles of cognitive behavioral therapy (CBT) [13][14]. These systems emphasize restructuring negative thoughts through surface-level reframing, offering encouragement, or reducing perceived threat. While such approaches are effective in many contexts, they present critical limitations when applied to structured, introspective frameworks like Inquiry-Based Stress Reduction (IBSR), which demands deeper cognitive engagement and personalized inquiry logic.

IBSR is distinct from CBT in both its method and goals. Instead of challenging the validity of thoughts through externally imposed logic, IBSR encourages users to investigate their thoughts through a sequence of self-generated questions (e.g., “Is it true?”, “Who would I be without that thought?”). This process requires a more nuanced, reflective, and individualized cognitive path that current AI systems—largely optimized for empathetic support or CBT-style reappraisals—are not equipped to handle. The limitation is not in the AI's ability to generate fluent text, but in its capacity to follow

through a coherent and recursive inquiry structure, something essential to IBSR but absent in mainstream chatbot architectures.

Moreover, most existing AI agents do not retain long-term conversational memory or conceptual coherence across sessions. This undermines the continuity required for IBSR practices, which often involve returning to prior emotional experiences, reassessing belief patterns, and tracking internal shifts. Without the ability to scaffold such cognitive depth, AI-only delivery risks turning IBSR into a mechanical or shallow process, which contradicts its core intention of cultivating internal awareness and non-judgmental reflection.

In essence, existing AI systems—while promising in low-intensity support—are structurally incompatible with the cognitive demands and process-orientation of IBSR. This limitation underscores the need for system redesigns that incorporate adaptive inquiry logic, conversational persistence, and contextual grounding. It also justifies the current study's choice to integrate IBSR with immersive VR environments, where embodied context can support not only emotional activation but also cognitive anchoring—both crucial to realizing the full therapeutic potential of IBSR.

2.4 Virtual Reality (VR) in Mental Health Interventions

Virtual Reality (VR) has emerged as a transformative technology in the domain of mental health interventions, particularly for disorders that involve avoidance-based symptomatology, such as social anxiety disorder (SAD). VR allows users to be immersed in three-dimensional social environments where interactions can be precisely controlled, repeated, and adapted to therapeutic goals. These environments simulate emotionally salient situations—public speaking, job interviews, small group conversations—while ensuring physical safety and therapeutic flexibility.

The core mechanism of most VR-based therapies is exposure. This is derived from behavioral models of anxiety, wherein repeated confrontation with anxiety-inducing stimuli leads to habituation and a reduction in avoidance behavior. A comprehensive meta-analysis of randomized controlled trials showed that Virtual Reality Exposure Therapy (VRET) leads to significant reductions in social anxiety symptoms, with effect sizes comparable to or exceeding those of traditional in vivo exposure therapies [15]. Follow-up data across 3-, 6-, and 12-month intervals confirmed that these benefits are sustained over time, supporting the long-term applicability of VR-based methods.

VR is particularly useful in activating affective and physiological responses critical for therapeutic processing. For example, participants exposed to virtual audiences or

ambiguous social feedback exhibit elevated heart rates, increased muscle tension, and measurable self-reported anxiety—responses that mirror those seen in real-world social threat contexts [16]. These findings confirm that VR can evoke ecologically valid fear responses, enabling meaningful emotional activation in therapeutic settings.

Most current applications of VR in mental health are embedded within Cognitive Behavioral Therapy (CBT) frameworks. In these models, VR serves as a contextual delivery system for exposure exercises: patients enter pre-scripted virtual scenes (e.g., giving a presentation to an unsupportive audience) while a human therapist guides them through cognitive reappraisal or coping strategies outside the VR environment [17]. The VR itself is not autonomous; it requires a trained therapist to interpret responses, ask probing questions, and facilitate learning transfer.

Some efforts have been made to use VRET as a standalone modality. These systems eliminate therapist involvement, relying solely on repeated exposure to reduce symptoms. While effective in reducing distress and avoidance behavior, these systems consistently underperform in shifting core beliefs, such as those related to self-worth, social judgment, or interpersonal failure. One study, for example, showed that VRET-only interventions were less effective than traditional CBT in changing maladaptive cognitive schemas at three-month follow-up, suggesting limitations in depth and generalization [18].

2.4.1 Limitations of VR: Why Exposure Alone Is Not Enough: Gaps in Current VR Therapy Models

While VRET has proven effective in reducing social anxiety symptoms, its clinical utility is limited by its narrow focus on exposure. In virtually all current implementations, the therapeutic logic revolves around the desensitization of emotional responses through repeated confrontation. This is suitable for modifying behavioral avoidance, but far less adequate for transforming cognitive structures, particularly the automatic thoughts and core beliefs that maintain anxiety.

One key limitation is the lack of cognitive inquiry embedded within the VR systems themselves. In most studies, the reflection, restructuring, and belief-challenging processes are handled externally—either by therapists in parallel sessions or through written homework. The VR environments are not designed to guide users through recursive questioning, track logical contradictions, or scaffold introspective thinking.

This poses a particular challenge for interventions like Inquiry-Based Stress Reduction (IBSR), which rely on structured, personalized questioning techniques (e.g., “Is it true?”, “Who would I be without that thought?”) to challenge underlying assumptions. Unlike CBT, which often targets specific thought distortions through therapist instruction, IBSR requires individuals to engage in internally-driven

introspection. Current VR systems are not equipped to support this level of cognitive engagement. They present static scenes and lack the conversational adaptability required for real-time belief exploration.

Furthermore, VR systems tend to be non-interactive or minimally interactive. Users are exposed to visual and auditory stimuli, but they do not engage in meaningful dialogues or adaptive interactions with avatars or AI agents. Most responses are pre-scripted and cannot adjust based on user reactions or emotional trajectories. This makes it difficult to deliver dynamic, responsive interventions that mirror the recursive, individualized nature of IBSR.

Finally, existing VR systems generally separate emotional activation from cognitive processing. Users experience anxiety in the VR setting but must process it cognitively elsewhere. This architectural separation fragments the intervention and reduces the potential for integrated therapeutic learning. Without scaffolding reflective thought within the VR context itself, interventions risk becoming superficial—treating symptoms but not causes.

In summary, while current VR-based interventions provide a compelling platform for emotional activation and behavioral exposure, they fall short of delivering deep, structured cognitive interventions such as IBSR. This limitation underscores the

rationale for the current study: to integrate AI-guided cognitive dialogue into VR environments, thereby enabling both the emotional intensity of VR and the cognitive depth of IBSR to coexist within a unified therapeutic experience.

2.5 Multi-Modal Interventions: Integrating VR and AI

In recent years, mental health interventions have increasingly moved toward multi-modal integration—particularly the combination of Virtual Reality (VR) and Artificial Intelligence (AI)—to address both emotional arousal and cognitive restructuring. This dual-channel approach is particularly relevant to disorders such as Social Anxiety Disorder (SAD), which involve both physiological stress responses and maladaptive belief systems.

Current implementations typically employ VR to simulate social-evaluative scenarios such as public speaking or being observed, thereby provoking useful anxiety responses for exposure therapy. AI components, meanwhile, are often introduced to provide scripted instructions, psychoeducation, or task-based feedback. Some advanced systems include personalization features based on biometric indicators or basic explainability modules (XAI) [19].

However, most existing systems treat VR and AI as parallel, loosely coupled modules: VR delivers emotional realism, while AI provides guidance or support. These

components rarely function as mutually adaptive parts of a unified therapeutic process. This limitation is especially pronounced in cognitive transformation frameworks such as Inquiry-Based Stress Reduction (IBSR), which require recursive reasoning, real-time feedback, and semantic depth.

2.5.1 Limitations of Current AI + VR Systems and the Rationale for This Study

Although both AI and VR have independently demonstrated therapeutic value, their current integration lacks the structural coherence necessary to support deep cognitive transformation. Particularly in belief-oriented interventions like IBSR, existing AI–VR combinations remain functionally superficial.

Most AI modules are limited to delivering pre-scripted prompts, diagnostic suggestions, or psychoeducational material. They do not support the full cycle of IBSR, which involves progressive self-questioning, personalized turnaround logic, and reflective belief contrast [19] [20]. Furthermore, these systems are often rigid, with limited capacity to respond meaningfully to user-specific emotional or cognitive feedback.

VR systems, on the other hand, are primarily designed for emotional activation. Although they successfully induce anxiety through realistic settings, they remain static

or semi-dynamic and are not contextually adapted to the user's evolving mental state. Critically, there is no established infrastructure to synchronize AI-driven cognitive shifts (e.g., a belief change) with changes in the VR environment.

To address these shortcomings, the system developed in this study enables real-time integration between the AI and VR modules. The AI component supports the full IBSR dialogue process—including all four key questions and personalized turnaround generation—while the Unity-based VR component receives AI output via API and dynamically updates scenes to reflect the user's current cognitive state.

2.5.2 Why the Proposed VR + AI System is More Effective

By bridging the functional gap between cognitive inquiry and emotional immersion, the proposed system establishes a tightly coupled feedback loop that overcomes the fragmentation seen in previous designs. At each stage of the IBSR process, the AI component semantically interprets the user's reflective state and communicates it to the VR engine in real time. For instance, once the AI detects that the user has progressed from identifying a stressful belief to formulating a turnaround, the VR scene transitions to a new symbolic environment representing this cognitive shift. This real-time semantic–visual alignment ensures that internal thought progression is

mirrored by external sensory input, reinforcing both emotional presence and cognitive clarity.

Figure 4 illustrates the comparative strengths and limitations of the four intervention groups tested in this study. The AI-only group demonstrates high cognitive depth, as it enables recursive dialogue and logical turnaround generation across all IBSR stages. However, emotional engagement is low, as users interact in a static, language-based interface devoid of immersive stimuli. In contrast, the VR-only group evokes strong emotional arousal by simulating anxiety-provoking environments, yet it lacks structured introspection, offering little support for belief transformation. Its linear, non-interactive format limits its cognitive impact.

Condition	Guidance Style	Emotional Engagement	Cognitive Depth	System Coupling	Overall Effectiveness
AI-only	AI dialogue (text/voice)	Low	High	Static, language-driven	Moderate (cognition-focused)
VR-only	Immersive exposure only	High	Low	Linear, scene-based	Moderate (emotion-focused)
AI + VR	Integrated guidance and scenes	High	High	Real-time semantic–visual sync	High (synergistic integration)
Human-facilitated	Adaptive, empathic interaction	Very High	Very High	Fully dynamic and personalized	Highest (benchmark)

Figure 4 Key Feature Comparison Across Four IBSR Intervention Modes

The AI+VR system outperforms both by integrating the semantic precision of AI-driven IBSR dialogue with the emotional intensity of immersive virtual environments.

Unlike prior systems where AI and VR functioned as isolated modules, the proposed design enables real-time synchronization between cognitive state and scene content. This alignment not only deepens user engagement but also grounds abstract cognitive work in emotionally resonant experiences. As a result, the AI+VR condition achieves high scores in both emotional and cognitive dimensions, delivering therapeutic synergy that neither modality could accomplish independently.

Despite this, the human-facilitated group remains the authoritative benchmark. Human guides excel in nuanced emotional regulation: they modulate tone, pacing, and word choice in response to real-time emotional cues, allowing them to calm, validate, or challenge the user in adaptive ways. Their capacity to perceive nonverbal signals—such as hesitation, silence, or vocal strain—enables dynamic interventions beyond the reach of current AI. Moreover, the therapeutic presence of a real person can enhance perceived trust and safety, which amplifies openness and deep introspection. Human facilitators can also integrate reflective pauses, empathy, and spontaneous insight, tailoring the pace and depth of inquiry to each individual's readiness and affective state. These qualities collectively explain why human-led IBSR still yields the most consistent outcomes, especially in emotionally complex cases.

However, the AI+VR system provides a scalable and semi-professional alternative capable of supporting structured self-inquiry and immersive engagement without

requiring therapist supervision. Its architectural integration allows emotional activation and cognitive restructuring to evolve in tandem, marking a departure from the piecemeal nature of previous digital interventions. Looking ahead, further enhancements such as affective speech synthesis may improve the emotional resonance of AI responses, narrowing the experiential gap between human-guided and AI-facilitated IBSR. Ultimately, the effectiveness of the proposed system does not stem from standalone advances in AI or VR, but from a mechanism-level coupling that allows real-time synergy between reflection and immersion. Under current technological constraints, this represents the most practically effective architecture for digital IBSR interventions.

2.6 Research Uniqueness and Research Gaps

Although considerable progress has been made in applying AI and VR to digital mental health, particularly in exposure therapy and psychoeducational guidance, most existing systems remain limited in their ability to support belief-level cognitive transformation. A critical gap persists: these interventions often rely on static scene delivery or scripted AI prompts and fail to offer a dynamic, semantically driven process capable of adapting to user-specific cognitive and emotional states. In belief-centered

frameworks such as Inquiry-Based Stress Reduction (IBSR), such rigidity fundamentally limits therapeutic depth.

To address this gap, the system introduced in this study integrates a fully interactive AI dialogue agent with a responsive, symbolic VR environment. Rather than using AI merely for instruction or using VR solely for immersion, this system achieves real-time coupling between user cognition and sensory feedback. As users engage in each stage of the IBSR process—identifying beliefs, questioning their validity, and exploring alternative perspectives—the AI interprets their reflective state and triggers corresponding transitions in the VR scenes. This structural alignment ensures that semantic inquiry and emotional immersion co-occur, reinforcing one another.

Figure 5 provides a comparative overview of six intervention modalities—covering AI-only, VR-only, and AI+VR conditions, both with and without the IBSR framework—evaluated across seven functional dimensions. These include cognitive depth, emotional engagement, adaptability of scenes, dialogue structure, user agency, core therapeutic function, and belief restructuring support.

Dimension	AI-only (non-IBSR)	AI-only (IBSR-based)	VR-only (non-IBSR)	VR-only (IBSR-scripted)	VR + AI (non-IBSR)	VR + AI (IBSR-integrated)
Core Function	Task instruction or CBT prompts	Text-based belief inquiry	Exposure simulation	Immersive scripted self-inquiry	Emotion-focused guidance	Immersive belief transformation
Cognitive Depth	Low	High (full IBSR)	Low	Medium	Medium	High
Emotional Engagement	Low	Low	High	High	High	High
Dialogue Structure	Pre-scripted or rule-based	Recursive open dialogue	Linear/no dialogue	Predefined question flow	Reactive feedback	Dynamic IBSR dialogue
Scene Adaptability	None	None	Fixed scenes	Limited branching	Some adaptation	Real-time adaptive scenes
User Agency	Medium	High	Low	Medium	Medium	High
Belief Restructuring Support	No	Yes	No	Partial	No	Yes

Figure 5 Comparison of Intervention Modalities Across IBSR and Non-IBSR Implementations

The analysis reveals that interventions lacking IBSR, regardless of whether they use AI or VR, tend to fall short in cognitive engagement and belief transformation. For example, non-IBSR AI systems may deliver task instructions or mental health tips but lack recursive questioning or contextual sensitivity. VR-only systems without IBSR can elicit emotional arousal through immersive visuals, yet they are typically linear and disconnected from users' internal states. Even traditional VR+IBSR models, which incorporate introspective questions within a virtual setting, remain limited by fixed sequencing and the absence of semantic integration.

In contrast, the proposed system—an AI+VR platform with integrated IBSR—achieves the most comprehensive performance across all dimensions. It supports deep cognitive reflection through recursive, personalized dialogue; it enhances emotional engagement via immersive, symbolic VR environments; and it synchronizes scene transitions with user insights in real time. Most importantly, this system is the only one among the six modalities capable of consistently supporting belief-level restructuring, thanks to its mechanism-level integration between the semantic logic of IBSR and the visual-emotional architecture of VR.

This research is therefore unique in its ability to offer not just a novel technological combination, but a new therapeutic paradigm—one that moves beyond static exposure or behavioral habituation and instead promotes structured introspection, emotional

anchoring, and cognitive change. By tightly coupling AI-driven reasoning with immersive, adaptive visuals, the system lays the groundwork for a new class of digital mental health tools that are both scalable and psychologically rigorous.

Chapter 3 Methodology and System Design

3.1 Research Framework and Hypotheses

This study aims to explore how the integration of Artificial Intelligence (AI) and Virtual Reality (VR), under the framework of Inquiry-Based Stress Reduction (IBSR), can be leveraged to reduce social anxiety more effectively. Based on prior research, traditional AI- or VR-based interventions typically address only partial aspects of anxiety treatment. VR excels in delivering immersive exposure experiences but often lacks guidance for deep cognitive reflection. Conversely, AI can provide structured dialogue for belief inquiry but lacks emotional stimulation and contextual immersion. This study therefore proposes that integrating AI and VR within an IBSR framework is more likely to facilitate both cognitive transformation and emotional engagement, thereby improving therapeutic outcomes.

To test this hypothesis, four experimental groups were designed:

- **AI-only Group**: Participants engage in a full IBSR dialogue via AI,

completing the four core questions and turnaround process using either text or voice interaction, without VR involvement.

- **VR-only Group**: Participants are immersed in pre-scripted VR scenarios designed in accordance with the IBSR flow, but with no AI-based cognitive guidance.
- **VR + AI Group**: Participants undergo a combined intervention where the AI guides the IBSR dialogue, and corresponding VR scenes dynamically switch in real-time based on detected cognitive shifts, maintaining alignment with the user's mental state.
- **Traditional IBSR Group**: Participants are guided through the IBSR process by a trained human facilitator in a face-to-face setting, serving as the baseline condition.

The theoretical framework of this study posits that social anxiety is fundamentally rooted in rigid, maladaptive beliefs about the self and others. Effective intervention therefore requires both emotional activation and belief-level cognitive restructuring. VR is used to evoke relevant emotional states, while the AI agent completes the IBSR process to support structured inquiry and turnaround. Their integration allows emotional experiences and cognitive shifts to co-evolve in a synchronized feedback loop.

Based on this framework, the following hypotheses are proposed:

- **H1**: All four IBSR-based intervention groups (AI-only, VR-only, VR + AI, and traditional) are expected to reduce participants' social anxiety levels to varying degrees post-intervention, though effect sizes may differ across groups.
- **H2**: The VR + AI group is expected to show significantly greater improvement in anxiety reduction compared to the AI-only and VR-only groups, demonstrating the advantage of multi-modal integration.
- **H3**: The VR + AI group is expected to achieve outcomes comparable to, but not significantly better than, the traditional human-facilitated IBSR group.

While the proposed system incorporates a dynamic linkage mechanism—whereby AI-detected cognitive changes trigger corresponding VR scene transitions—this emotional-cognitive synchronization is not directly measurable in the current study due to the absence of a dedicated rating scale or behavioral metric. As such, this mechanism is not posed as a testable hypothesis, but will be discussed as a theoretical implication and direction for future research.

Through this framework, the study not only allows for the comparison of different intervention modalities but also deepens our understanding of the synergy

between immersive experience and belief transformation—contributing new insights to the design of multi-modal digital mental health interventions.

3.2 Research Target Groups

This study focuses on non-clinical young adults aged mainly 18 to 29 who may experience mild to moderate symptoms of social anxiety but have never been formally diagnosed with Social Anxiety Disorder (SAD). These individuals may occasionally feel nervous in social settings, fear being judged, or avoid certain social situations, yet do not meet clinical criteria. Studying this group allows for an evaluation of how IBSR-based digital interventions may support early-stage emotional regulation and belief restructuring.

3.2.1 Inclusion Criteria

Participants were aged between 19 and 32 years, with self-reported signs of social discomfort such as fear of being judged, avoidance of public speaking, or unease in group settings. While the study primarily targeted young adults aged 18 to 29—based on epidemiological data identifying this group as the most affected by Social Anxiety Disorder (SAD)—a small number of participants slightly outside this range were

accepted due to recruitment and resource limitations. For instance, only one participant was aged 32, while the vast majority fell within the intended age range.

A score above the mild threshold on the Social Interaction Anxiety Scale (SIAS) was preferred but not strictly required for inclusion. All participants had no prior exposure to Inquiry-Based Stress Reduction (IBSR), Cognitive Behavioral Therapy (CBT), or other structured cognitive inquiry methods. Individuals with a formal psychiatric diagnosis, including SAD or related conditions, were excluded. Additionally, participants were expected to be open to using digital tools such as AI dialogue systems or VR platforms, although no advanced technical proficiency was necessary.

3.2.2 Exclusion Criteria

Participants were excluded if they were currently receiving psychological treatment or taking psychoactive medication. Individuals with diagnosed psychiatric or neurological disorders—such as depression, bipolar disorder, schizophrenia, or epilepsy—were also not eligible. Additional exclusion criteria included prior professional training or long-term involvement in psychotherapy, mindfulness practices, or cognitive therapy. Finally, participants with a strong aversion to immersive environments, or with a history of trauma or motion sickness associated with virtual reality, were excluded to

ensure comfort and safety during the intervention.

3.2.3 Group Design and Sample Distribution

A total of 80 participants will be recruited through online platforms, university channels, and mental health networks. After eligibility screening and informed consent, participants will be randomly and independently assigned to one of four experimental groups, with 20 individuals in each: AI-only, VR-only, AI + VR, and human-led IBSR.

Group assignment is stratified based on gender and SIAS score ranges to maintain baseline balance across all conditions. Each participant is assigned to only one group, with no crossover between conditions.

3.3 Experimental Group Design

To investigate the effects of different technological delivery modes of Inquiry-Based Stress Reduction (IBSR), the study employed a four-group randomized design. While all groups followed the same cognitive process—centered around the four IBSR questions and turnaround generation—they differed in how the intervention was delivered: through AI, VR, both technologies in tandem, or human facilitation. Each group consisted of 20

independent participants (n = 80 in total), with participants randomly assigned to ensure balanced baseline characteristics.

3.3.1 AI-only Group

Participants in this group interacted exclusively with a conversational AI system to complete the full IBSR (Inquiry-Based Stress Reduction) process, including belief identification, the four structured questions, emotional response exploration, and

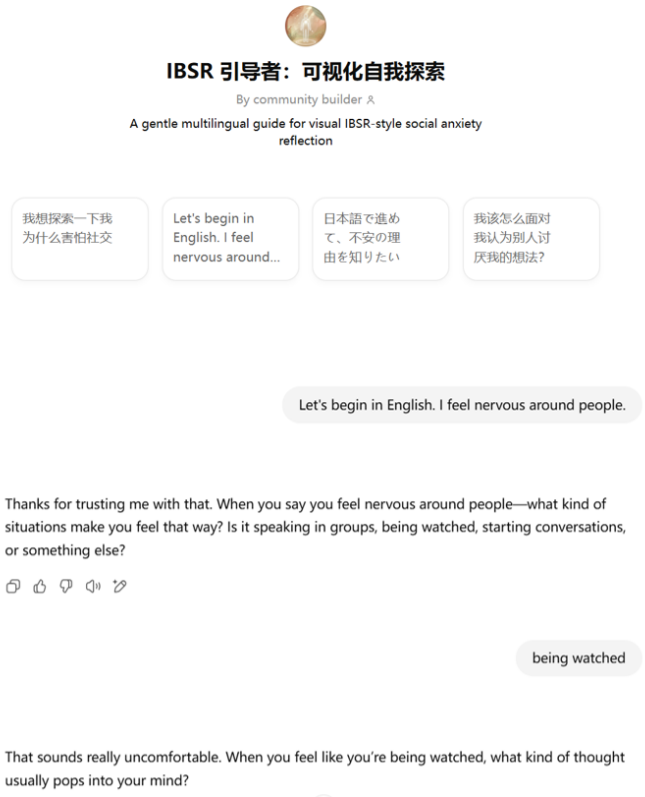

Figure 6 Sample Dialogue in the AI-Only Condition: User Initiation and Early Emotional Inquiry in English

personalized turnaround generation. The objective was to evaluate whether a trained AI

agent could independently facilitate cognitive restructuring without relying on visual immersion or environmental context.

The system was developed based on OpenAI's GPT-4 architecture (ChatGPT) and deployed locally to ensure data privacy and real-time responsiveness. The user interface was built using Python and enabled low-latency bidirectional communication via WebSocket. The system supported both text and voice modalities, allowing participants to choose whether to communicate with the AI through spoken dialogue or typed input according to their preference. Voice input was transcribed using Whisper API, while

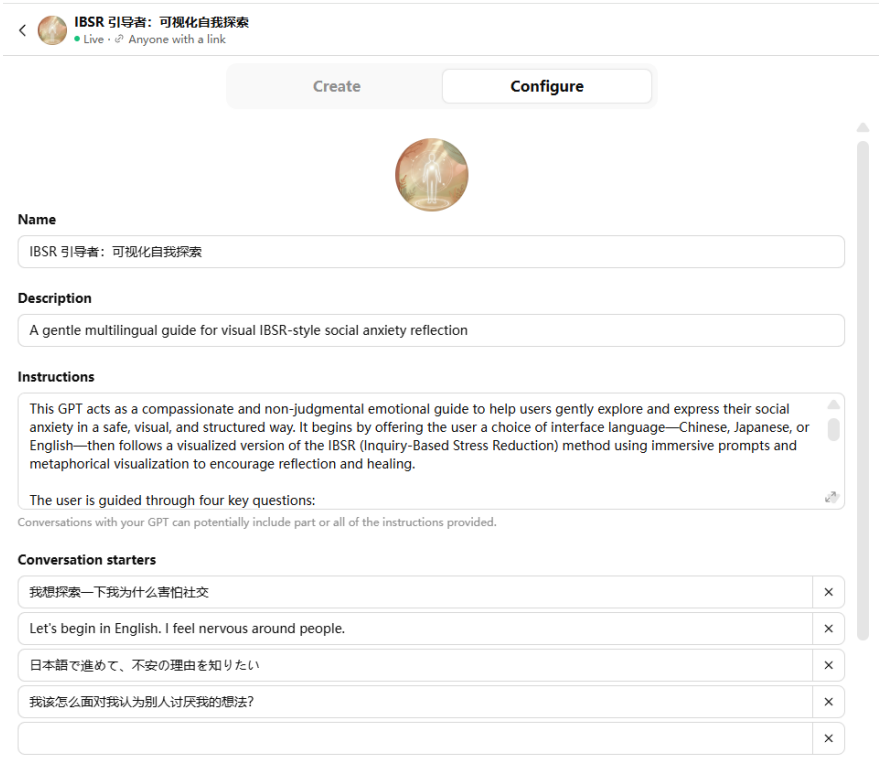

Figure 7 Prompt Configuration and Interface Overview of the Custom GPT Agent for IBSR-Based Social Anxiety Reflection

voice output was synthesized using either ElevenLabs or Microsoft Edge TTS engines to deliver emotionally expressive and natural-sounding speech.

Technically, the system comprised three primary modules: the dialogue engine, a session-state tracker, and a prompt orchestration framework. The dialogue engine handled real-time semantic interaction with the user. The session tracker maintained memory of the user's current IBSR stage to ensure smooth progression through the inquiry cycle. The prompt framework ensured that all AI outputs conformed to the tone and structure of an IBSR facilitator and dynamically adapted the guidance strategy depending on the stage of reflection.

At the beginning of each session, a high-level system prompt was injected, instructing the AI to adopt the role of a warm and empathetic IBSR-trained guide. This instruction included procedural logic for the four questions, tone constraints, recognition of belief statements and emotional responses, and turnaround-generation strategies. User inputs were internally tagged with semantic markers such as belief_statement, emotional_reaction, or turnaround_candidate to aid the model in understanding conversation context. In addition, a set of few-shot dialogue examples based on real IBSR facilitation practices was embedded into the system prompt during model initialization. These examples encompassed diverse belief types, emotional responses, and guidance flows (e.g., self-critical versus externally directed beliefs),

allowing the AI to not only follow structural instructions but also emulate the tone and phrasing of a skilled human facilitator. This few-shot scaffolding improved the model’s capacity to interpret ambiguous or emotionally nuanced inputs and helped sustain a warm, nonjudgmental dialogue style throughout the interaction.

The conversation followed a recursive modular pipeline. The AI first asked the user to describe a specific stressful social scenario and helped identify the underlying belief. It then guided the user through the four canonical IBSR questions: (1) Is it true? (2) Can you absolutely know it's true? (3) How do you react when you believe that thought? (4) Who would you be without that thought? Once the four questions were completed, the AI synthesized one or more candidate turnaround statements based on prior responses and invited the user to refine, adjust, or reflect on these alternatives.

Internally, the system used memory tokens to track conversational state and detect whether a user had fully responded to a question. If a step was skipped or unclear, the AI would automatically reframe or revisit it. Dialogue context was maintained locally across turns, ensuring continuity and coherence in semantic flow.

Without relying on visual immersion or external stimuli, the AI-only condition achieved structured IBSR guidance purely through semantic reasoning, session-state management, and prompt design. This configuration served as a technically controlled

benchmark for evaluating the AI's standalone capability to guide belief-oriented inquiry.

3.3.2 VR-only Group

Participants in this group experienced a series of pre-rendered virtual reality (VR) scenes delivered through the Meta Quest Pro headset. The VR system was developed using Unity (version 2022.3.0f1) and integrated with the OpenXR framework to ensure precise spatial tracking and device compatibility. The entire application was deployed locally on the headset, eliminating the need for an external server and ensuring operational stability and data privacy throughout the experiment.

The VR scenes were designed around core emotional and cognitive constructs commonly associated with social anxiety and the IBSR (Inquiry-Based Stress Reduction) method. These constructs included fear of negative evaluation, internalized self-judgment, and imagined interpersonal failure. Each concept was represented through visual metaphors—for example, open clear spaces symbolized cognitive release, enclosed or darkened environments conveyed psychological constriction, and sudden thunderstorms or lighting changes reflected emotional turbulence. Scene transitions were also used to illustrate changes in perspective, such as moving from darkness to light or from isolation to openness, thereby encouraging emotional resonance and introspective engagement.

Each scene was paired with a pre-recorded audio narration that followed the four canonical IBSR questions in sequence: (1) Is it true? (2) Can you absolutely know it's true? (3) How do you react when you believe that thought? (4) Who would you be without that thought? The narration was scripted in advance and remained fixed during playback, with no interactive dialogue or adaptive feedback mechanisms. Participants could not provide any verbal or behavioral input, and the system did not track or respond to their emotional states. This design constraint was intentional, as it enabled isolation of the therapeutic impact of immersive visualization and guided reflection without the influence of real-time AI interaction.

From a technical standpoint, the VR application followed a modular script architecture written in C#. The major components included:

- MainManager.cs: The core controller responsible for initiating the experience, managing the session state, and coordinating audio playback and scene flow.
- SceneManager.cs: Controlled the loading and sequencing of all VR environments, ensuring a linear progression through the IBSR-aligned experience.
- XRRootManager.cs: Managed spatial positioning, headset integration, and real-time tracking using the OpenXR framework to maintain immersive

fidelity.

- MainContrastManager.cs: Contained predefined language templates for IBSR narration, ensuring logical coherence and emotional consistency in guidance.
- LanguageType.cs: Defined the available language options (Chinese, Japanese, and English), which participants could select prior to the session.
- StartPoint.cs: Established the default spatial orientation and entry point for each session, ensuring that all users began with a consistent visual and positional frame.

Although the system also included a MemoryBubbleManager.cs module designed to manage symbolic UI elements such as “thought bubbles,” this module was disabled in the VR-only condition to avoid introducing any interactive or personalized components. The experience was entirely passive and uniform across all participants in this group.

In summary, the VR-only system was intentionally designed to operate as a fixed, non-adaptive immersive environment. It offered emotionally evocative scenes and IBSR-aligned audio guidance without real-time user interaction. This controlled configuration allowed the study to evaluate whether immersive, symbolically rich visualization alone—when combined with non-interactive reflective narration—could elicit meaningful emotional arousal or cognitive priming in the absence of semantic reasoning or dialogic

AI support.

3.3.3 VR + AI Group

This group extended the immersive virtual reality experience by integrating a real-time interactive AI guidance system. The aim was to examine whether the synchronization between cognitive restructuring and emotional immersion could enhance the depth and efficacy of IBSR-based interventions. Participants wore the Meta

Figure 8 VR+AI Group Engaging in Visual IBSR with Meta Quest Pro and ChatGPT-Based Dialogue

Quest Pro headset and viewed the same visual scenes as those used in the VR-only

group. However, unlike the previous group's fixed playback format, the system in this condition was capable of receiving live user input and dynamically adjusting both guidance content and scene progression based on semantic analysis performed by the AI.

At the core of the system was an AI module powered by a large language model (ChatGPT), integrated into the Unity environment via the RealtimeAPIWrapper.cs script. Each user input was passed in real time to the ChatManager.cs module, which

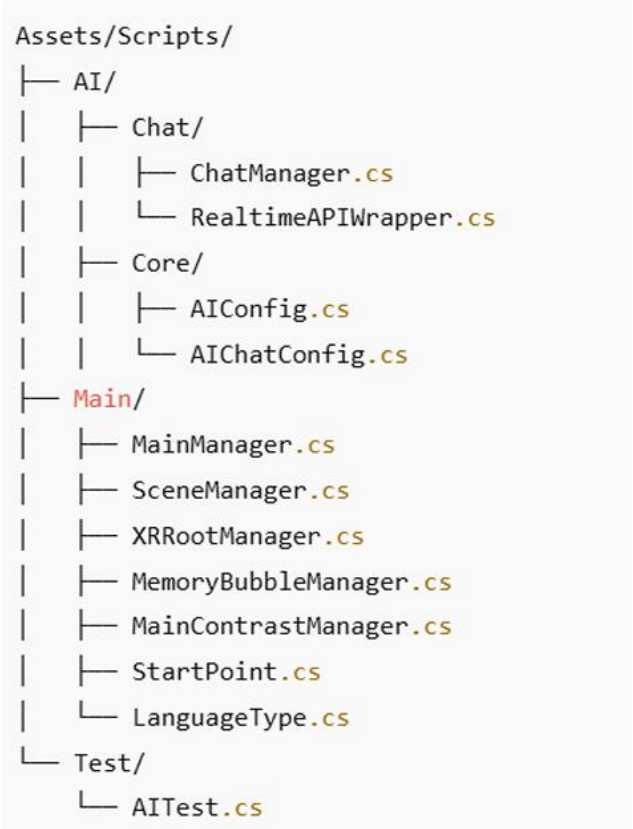

Figure 9 Project Directory Structure

tracked the current dialogue context to ensure coherent and targeted semantic guidance. When the AI detected a positive cognitive shift—such as a transition from "I'm not

good enough" to "I've done my best"—an internal trigger mechanism initiated an immediate change in the VR scene, thereby reinforcing the emotional resonance associated with the user's transformation in belief.

Technically, the system employed a local inter-process communication (IPC) mechanism between the Unity application and the AI backend, enabling real-time integration of semantic results without relying on external servers. This minimized latency and reduced privacy risks. Upon receiving signals from the AI, the SceneManager.cs script instantly executed the corresponding VR scene transitions. For example, when a user released a limiting belief, a previously dark and enclosed environment might shift to a bright, open natural landscape, providing visual feedback aligned with the user's internal emotional release.

The entire session was orchestrated by the MainManager.cs module, which coordinated the timeline, audio playback, and scene flow. Standardized language templates aligned with the IBSR logic were generated using the MainContrastManager.cs module to construct AI output with semantic consistency and psychological coherence. Multilingual functionality remained available through the LanguageType.cs module, allowing participants to communicate in English, Chinese, or Japanese.

Compared to the VR-only group, this condition introduced dynamic feedback and a semi-open procedural flow. Scenes no longer followed a fixed sequence but adapted in real time to the pacing and content of the user–AI dialogue. As a result, the VR environment evolved from a static immersive medium into an empathic co-facilitator—capable of reflecting the user's internal changes through external visual shifts. This design enabled a bidirectional fusion of cognitive insight and emotional regulation, reinforcing the therapeutic objectives of IBSR through personalized and emotionally responsive engagement.

3.3.4 Traditional IBSR Group

This group followed the conventional format of IBSR facilitation, in which a professionally trained facilitator—certified in the IBSR method and experienced in its practical application—conducted the entire session in person or via online meetings. The facilitator asked the four core questions, guided the generation of turnarounds, and adapted the pacing and language according to the participant's emotional and cognitive responses.

This group served as a baseline for evaluating the effectiveness of digital delivery formats. It enabled the study to assess how closely AI- and VR-based systems can

replicate the depth and impact of cognitive interventions facilitated by certified human professionals.

3.4 Participant Recruitment and Ethical Protocol

Participants for this study were recruited through university mailing lists, online communities, and digital flyers directed at young adults between the ages of 19 and 32. Inclusion criteria required participants to self-report some degree of social discomfort—such as fear of negative judgment, avoidance of social performance situations, or uneasiness in groups. Although a score above the mild threshold on the Social Interaction Anxiety Scale (SIAS) was preferred, it was not mandatory, aligning with previous research approaches that included subclinical populations for early intervention studies [22].

To preserve cognitive neutrality and ensure that participants entered the study without prior structured cognitive intervention exposure, individuals who had previously participated in programs such as Inquiry-Based Stress Reduction (IBSR), Cognitive Behavioral Therapy (CBT), or mindfulness-based therapies were excluded. This mirrors approaches taken in past IBSR studies that focused on naïve populations to isolate intervention effects more reliably [21]. In addition, individuals with a clinical

diagnosis of any psychiatric or neurological condition (e.g., Social Anxiety Disorder, depression, schizophrenia, epilepsy), those currently receiving psychological treatment or taking psychoactive medications, and those with formal training in psychotherapy or long-term practice in reflective therapies were excluded.

Participants were required to demonstrate openness to interacting with digital systems such as AI chatbots and virtual reality environments. However, previous technical experience was not required, as the system supported both voice and text interfaces and provided guided onboarding instructions to all users.

Eighty participants in total were selected and evenly divided into four non-overlapping groups: AI-only, VR-only, VR + AI, and Human-Facilitated IBSR. Each group contained 20 participants, with no individual assigned to more than one group. Assignment was random to minimize baseline differences.

This study was approved in advance by the SDM Ethics Committee (SDM 倫理審査委員会) of Keio University. All participants received a detailed explanation of the study's aims, procedures, and potential risks. Written informed consent was obtained from each participant, and they were informed of their right to withdraw from the study at any time without penalty. All participant data were anonymized, encrypted, and stored in accordance with institutional privacy and data protection policies.

Furthermore, all data were stored exclusively on Keio University's official Google Drive system and not saved on any personal device.

3.5 Measurement Tools

To rigorously evaluate the effectiveness of the four intervention formats in this study, a standardized quantitative tool was adopted to measure participants' levels of social anxiety before, immediately after, and one week after the intervention. The chosen instrument is the Social Interaction Anxiety Scale (SIAS)—a widely validated self-report questionnaire specifically designed to assess anxiety symptoms in social interaction contexts.

The SIAS was administered at **three time points**:

1. **T1 – Pre-Intervention (Baseline):** To assess the participants' initial social anxiety status;
2. **T2 – Immediate Post-Intervention:** On the same day the final session was completed;
3. **T3 – Delayed Follow-up (7 Days Later):** To examine the persistence or attenuation of effects after one week.

This three-point measurement design allows the study to track both the short-term

relief and medium-term retention of therapeutic impact. This approach is well-supported by prior studies that evaluate both cognitive and behavioral interventions for social anxiety using repeated SIAS testing over time [23][28].

Given the focus of this research on belief-oriented interventions (via IBSR), rather than solely on behavioral desensitization, SIAS was selected not only for its diagnostic strength but also because it can sensitively detect changes even in subclinical and general population groups—such as university students who experience social unease but have no formal SAD diagnosis [26][30].

3.5.1 Social Interaction Anxiety Scale (SIAS)

The SIAS is a 20-item Likert-scale questionnaire developed by Mattick and Clarke to measure the distress people feel when engaging in social interaction, particularly with strangers or in evaluative situations. Each item is rated on a 0–4 scale (0 = not at all, 4 = extremely), with a total score ranging from 0 to 80. Higher scores indicate more severe social interaction anxiety [23][24].

Psychometrically, the SIAS is known for its high internal consistency (Cronbach's $\alpha > 0.90$) and strong test–retest reliability [25][26]. It has been validated across both clinical and non-clinical populations, and has proven effective in detecting subtle symptom changes in short-term interventions [27]. These characteristics make it

especially well-suited for this study's sample of non-diagnosed individuals experiencing social discomfort.

Moreover, the SIAS has demonstrated robust sensitivity across various delivery formats, including traditional therapy, internet-based self-help, and VR-mediated environments [23][28]. In particular, it has shown reliability in capturing anxiety fluctuations in participants undergoing brief, structured programs like CBT or IBSR-inspired methods.

It is important to note that although the SIAS is effective in capturing behavioral and emotional anxiety symptoms—such as avoidance or fear of eye contact—it does not directly measure deep cognitive belief restructuring, which is the core focus of IBSR. As such, while SIAS serves as a valuable quantitative anchor in this study, its limitations are acknowledged when interpreting long-term cognitive transformation outcomes [29][30].

Finally, the SIAS has also been validated in non-Western cultural contexts, including East Asia, where norms around social hierarchy and public evaluation differ from Western settings. Cross-cultural studies suggest that although some items may require minor semantic adaptation, the overall factor structure remains stable, making it suitable for diverse populations like those in this study [31][32].

3.6 Experiment Procedure and Timeline

This study employed a one-time intervention structure to evaluate the comparative effectiveness of four distinct IBSR-based psychological support formats: AI-only, VR-only, AI + VR, and traditional human-facilitated IBSR. Each participant received a single intervention session, followed by two assessment checkpoints to measure changes in social interaction anxiety over time—one immediately after the intervention and another seven days later.

The experimental process began with participant screening and informed consent. Individuals were first invited to complete an online intake form, which included basic demographic questions, self-reported indicators of social anxiety, and a baseline assessment using the Social Interaction Anxiety Scale (SIAS). Those who met the inclusion criteria were provided with full information about the research objectives, methods, and data usage policies, and were asked to sign a digital informed consent form. The entire study protocol was reviewed and approved by the SDM Ethics Review Committee of Keio University.

On the scheduled experiment day (Day 0), each participant engaged in a single IBSR-based intervention session corresponding to their assigned group. Participants in the AI-only group interacted with a specially trained conversational agent powered by a

fine-tuned ChatGPT model. The AI guided users through the complete IBSR cycle, either through voice or text interface, helping them identify a stressful belief, reflect on it using the four canonical questions, and then generate personalized turnaround statements.

Participants in the VR-only group experienced a fixed sequence of immersive VR environments. Each scene was designed to reflect a stage in the IBSR dialogue script, with pre-recorded voice prompts used to guide users through the reflective process. However, these prompts and scenes were static and did not respond to user input or belief changes.

In the VR + AI group, the AI system was integrated directly into the VR environment using Unity APIs. As the participant proceeded through the IBSR process with the AI, any detected cognitive shift—for example, from “I am not good enough” to “I am doing my best”—triggered a real-time change in the VR scene, such as a transition from a confined indoor space to an open natural environment. This design allowed emotional immersion and cognitive restructuring to occur in synchrony.

For the human-facilitated IBSR group, a trained facilitator conducted a live session based on the original IBSR protocol. Participants were verbally guided through the full

inquiry process in person, with the facilitator adapting prompts in real time based on participant responses.

Immediately after the intervention (still on Day 0), all participants were asked to complete the SIAS questionnaire for a second time. This post-test was administered on site to assess the short-term effects of the intervention on social anxiety symptoms. A follow-up evaluation was then conducted exactly seven days later. Participants received an online link to the SIAS questionnaire and were instructed to complete it remotely, providing data on whether any therapeutic effects were sustained beyond the session.

The entire timeline, consisting of a single intervention and two assessment points (pre- and post-session, and one-week follow-up), reflects a structure commonly used in digital mental health research. It allows for the evaluation of both immediate symptom reduction and the short-term persistence of belief-level interventions like IBSR [33].

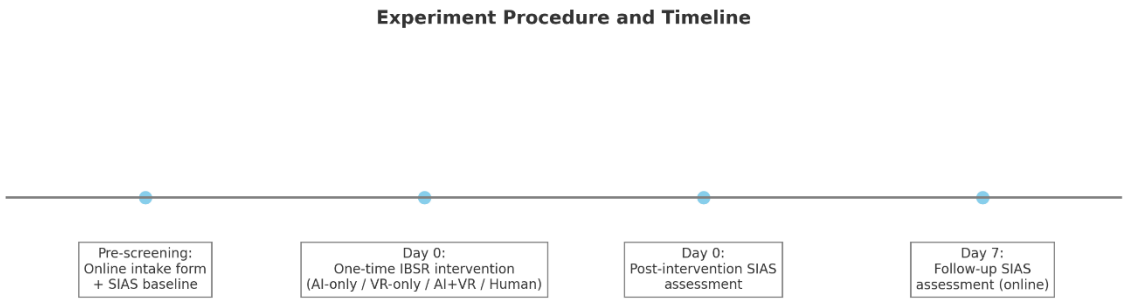

Figure 10 Timeline of the Experimental Procedure

3.6.1 Justification for Single-Session IBSR Intervention Design

This study employs a single-session design for implementing the Inquiry-Based Stress Reduction (IBSR) method, grounded in both theoretical logic and validated empirical support. IBSR is inherently structured as a self-contained cognitive process: participants identify a stressful thought, explore it using four guided questions, and generate turnaround statements that challenge and reframe the original belief. This structured cognitive loop is designed to activate insight and belief transformation through deep reflective inquiry. Its efficacy does not rely on repeated exposure but rather on the participant's willingness to engage meaningfully with a single cognitive pattern.

Empirical evidence affirms that IBSR can be effective even when applied in short-term or single-session formats. For example, one study has explicitly stated that IBSR may serve as a stand-alone or brief intervention model, capable of producing perceptual and emotional shifts when the process is delivered in a structured manner and the participant exhibits cognitive openness. This highlights the flexibility and depth of the method even without ongoing therapist involvement [11]. Another investigation that included IBSR techniques within a one-week mindfulness-based stress reduction program also demonstrated measurable reductions in emotional strain, further reinforcing the suitability of brief formats for inducing psychological change [34].

Additionally, field experience supports the notion that individuals often report emotional relief, cognitive distancing, or mental clarity after completing just one structured IBSR session. When paired with immersive technologies such as VR and AI-based dialogue, the emotional engagement is further amplified, enhancing the potential for meaningful cognitive shifts within a single exposure.

Given these theoretical, empirical, and practical foundations, the current study adopts a one-time intervention across all experimental groups to allow direct comparison between different delivery formats (AI-only, VR-only, AI+VR, and human-facilitated IBSR). This design reduces dropout risk, maintains methodological consistency, and reflects how structured digital interventions can yield real-time cognitive and emotional benefits.

3.7 Scene Logic and Interaction Design for AI-Responsive IBSR in VR

The VR + AI system was constructed as a dynamic feedback loop that closely aligns each visual scene with the cognitive purpose of the four IBSR (Inquiry-Based Stress Reduction) questions. Instead of using VR as a static display, each stage of the IBSR process is mapped onto a symbolic virtual environment to support both emotional immersion and cognitive inquiry.

Scene 1 corresponds to the first IBSR question: *"Is it true?"* This stage initiates the user's reflective journey. A calm and open landscape provides a neutral space for contemplation. As the user verbalizes their stressful belief, the AI captures it and renders the statement into floating memory bubbles, visually externalizing the thought and prompting metacognitive awareness. This helps users see the belief as an object to examine, not a fact to accept.

Scene 2 supports the second IBSR question: *"Can you absolutely know it's true?"* While maintaining the same spatial environment, subtle shifts in lighting and tone evoke a sense of uncertainty or doubt. The goal is not to distract but to deepen introspection. This stability allows users to question the validity of the belief in a grounded mental space.

Scene 3 mirrors the emotional charge tied to the third IBSR question: *"How do you react when you believe that thought?"* When the AI detects heightened distress in the user's voice or content, the scene transitions into a storm with thunder, wind, and darkness. This dramatic transformation reflects the emotional impact of holding the belief and encourages the user to fully feel and articulate their inner reactions.

Scene 4 represents the fourth IBSR question: *"Who would you be without that thought?"* When the user expresses release, insight, or a shift toward self-compassion,

the AI dynamically switches to a serene scene—such as a beach or forest—signifying cognitive transformation and emotional relief. The bright atmosphere affirms the possibility of peace without the limiting thought.

Figure 11 VR Scene Progression Aligned with IBSR Stages in the AI + VR Condition

The system relies on real-time integration between ChatGPT (via RealtimeAPIWrapper.cs) and Unity. SceneManager.cs handles transitions based on the AI's classification of user responses into states such as "hold," "doubt," "distress," or "release." This feedback architecture allows the virtual environment to respond meaningfully to the cognitive stage of the user's journey—maintaining fidelity to the IBSR process while enhancing emotional resonance.

Chapter 4 Experiments and Results Analysis

4.1 Participant Demographics and Pre-test Screening

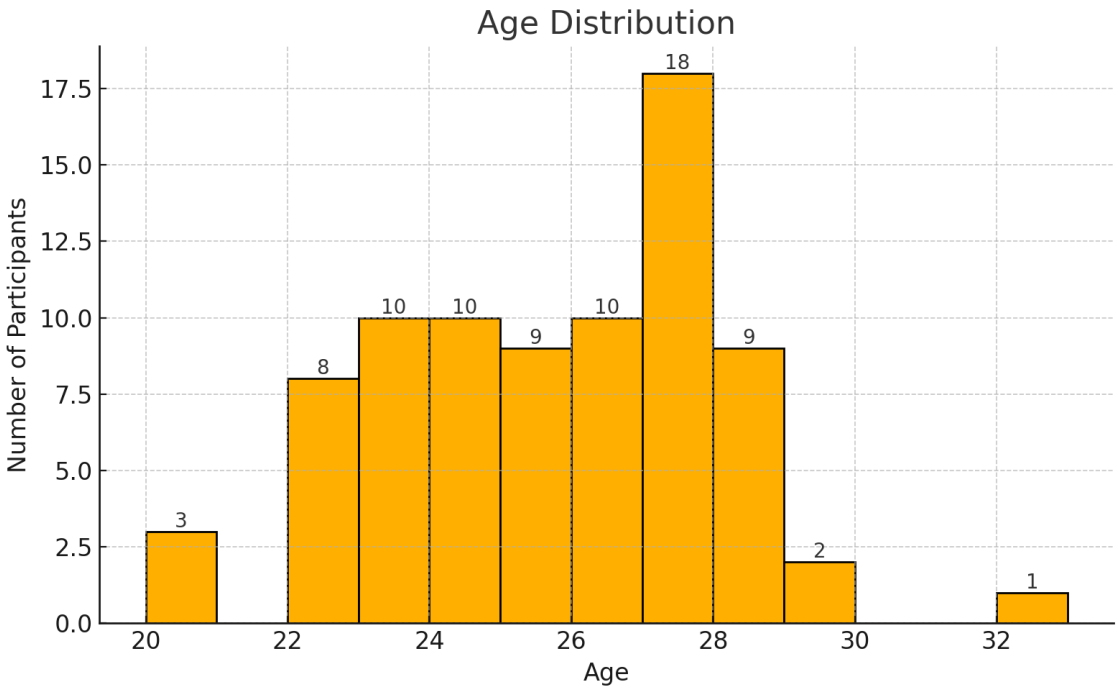

Table 1 Age Distribution of Study Participants

A total of 80 participants were successfully recruited and randomly assigned into four experimental groups of equal size (n = 20): AI-only, VR-only, AI + VR, and human-facilitated IBSR. These groups correspond to different delivery formats of the Inquiry-Based Stress Reduction (IBSR) intervention, allowing for a controlled comparison of AI- and VR-based modalities both in isolation and in integration.

The participants ranged in age from 19 to 32 years, with a mean age of 25.01 years (SD = 3.41). The age distribution was skewed toward young adults in their early to late twenties, as shown in **Table 1**, with the majority falling between 22 and 29

years. This age range reflects a demographic segment that is particularly susceptible to subclinical social anxiety, especially in educational and early professional settings. Importantly, all participants demonstrated basic digital literacy sufficient for engaging with AI and VR interfaces, though advanced technical expertise was not required.

Gender distribution was relatively balanced, with 44 females (55%) and 36 males (45%). As illustrated in **Table 2**, this gender composition was evenly spread across all four experimental groups, helping to control for gender-based bias and enabling exploratory analysis of any potential gender-related differences in intervention efficacy.

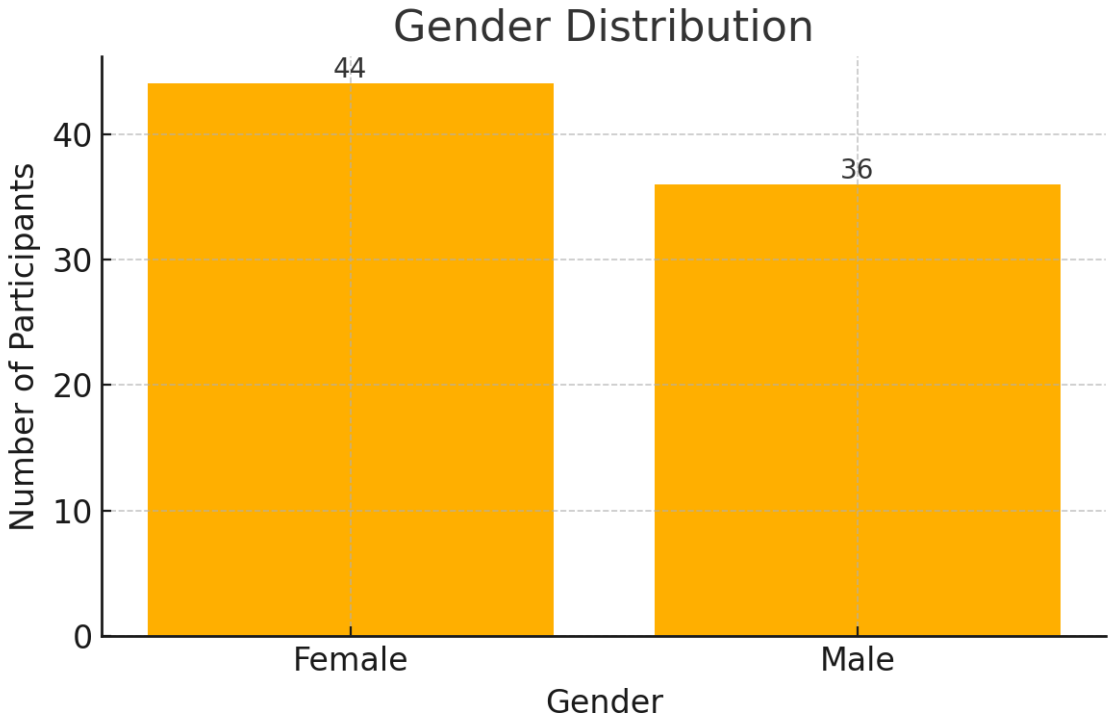

Table 2 Gender Distribution of Study Participants

Prior to the intervention, all participants completed an online screening process

consisting of demographic questions, self-reported indicators of social discomfort (such as fear of being judged, anxiety in group settings, or avoidance of public speaking), and the baseline Social Interaction Anxiety Scale (SIAS) questionnaire. Although the study prioritized participants with SIAS scores above 36—a commonly cited threshold for clinical relevance—this was not a strict inclusion criterion. Instead, the study intentionally focused on individuals with elevated but undiagnosed levels of social anxiety, ensuring that the sample represented a non-clinical yet intervention-relevant population.

To preserve internal validity, only participants without prior exposure to IBSR, Cognitive Behavioral Therapy (CBT), or similar structured cognitive interventions were included. All participants reported no history of psychiatric or neurological diagnoses, nor current use of psychoactive medication. This ensured that the results would reflect the effects of the intervention format itself rather than confounding factors related to previous treatment or clinical conditions.

1. Pre-Intervention Data Comparison

ANOVA Results

Group (Mean ± SD)	AI + VR (n = 20)	AI Only (n = 20)	Traditional IBSR (n = 20)	VR Only (n = 20)	F^B	p^B
SIAS_Before	38.400 ± 7.141	38.200 ± 6.510	40.200 ± 6.526	39.900 ± 8.058	0.415	0.743

- $p < .1$ ** $p < .05$ *** $p < .01$

Table 3 Pre-Intervention Data Comparison

Baseline SIAS scores were statistically analyzed using one-way ANOVA, revealing no significant differences across the four groups ($F = 0.415$, $p = 0.743$) in **Table 3**, thereby confirming the equivalence of anxiety levels prior to intervention. As shown in **Table 4**, all groups scored above the clinical threshold of 36: the AI + VR group had a mean of 38.40, AI-only 38.20, VR-only 39.90, and the traditional IBSR group 40.20. These results validate that, although the participants were not formally diagnosed with Social Anxiety Disorder (SAD), their reported levels of social discomfort were both meaningful and appropriate for testing therapeutic efficacy.

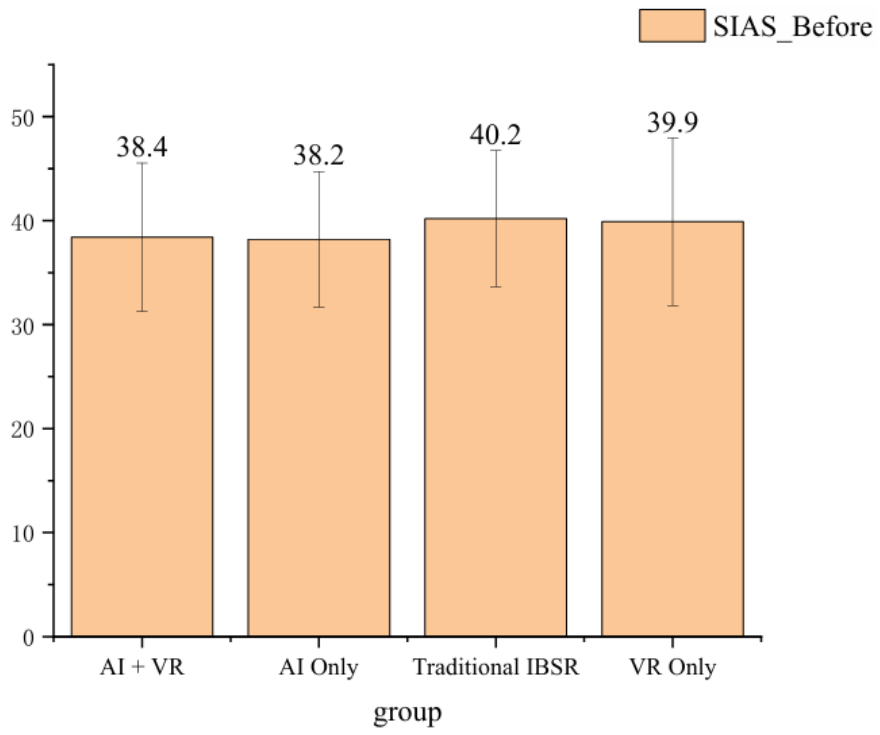

Table 4 Pre-Intervention SIAS Scores Across All Groups

In summary, the participant pool was well-aligned with the study's objectives: young adults with observable but undiagnosed social anxiety, no prior therapeutic

training, and sufficient digital familiarity. The even gender distribution and equivalent baseline anxiety levels across groups provide a solid foundation for evaluating the comparative outcomes of the different IBSR delivery methods.

4.2 Immediate Post-Intervention Results Analysis

Following the one-time intervention session, all participants completed an immediate post-assessment using the Social Interaction Anxiety Scale (SIAS) to evaluate short-term treatment effects. As shown in Table 5, a one-way ANOVA revealed a statistically significant difference among the four groups in their post-intervention SIAS scores ($F = 7.055$, $p < 0.001$). This indicates that the type of intervention had a substantial influence on anxiety reduction.

2. Post-Intervention (Same-Day) Data Comparison

ANOVA Results

Group (M ± SD)	AI + VR (n = 20)	AI Only (n = 20)	Traditional IBSR (n = 20)	VR Only (n = 20)	F^B	p^B
SIAS_After	28.650 ± 6.063	33.000 ± 6.274	25.900 ± 5.057	33.750 ± 7.369	7.055	0.000 ***

- $p < .1$ ** $p < .05$ *** $p < .01$

Table 5 Post-Intervention (Same-Day) Data Comparison

Specifically, participants in the Traditional IBSR group exhibited the most pronounced improvement, with a mean post-test score of 25.90. This score was significantly lower than those of all other groups ($p < 0.01$), underscoring the robust efficacy of classical structured cognitive inquiry methods in alleviating social anxiety. The next most effective group was the AI + VR group, with a mean score of 28.65. This group performed significantly better than both the AI-only group ($M = 33.00$, $p = 0.004$) and the VR-only group ($M = 33.75$, $p = 0.011$), demonstrating a synergistic effect between AI-guided dialogue and immersive emotional engagement. In contrast, no significant difference was observed between the AI-only and VR-only groups ($p = 0.482$), and both groups had relatively higher SIAS scores, indicating weaker

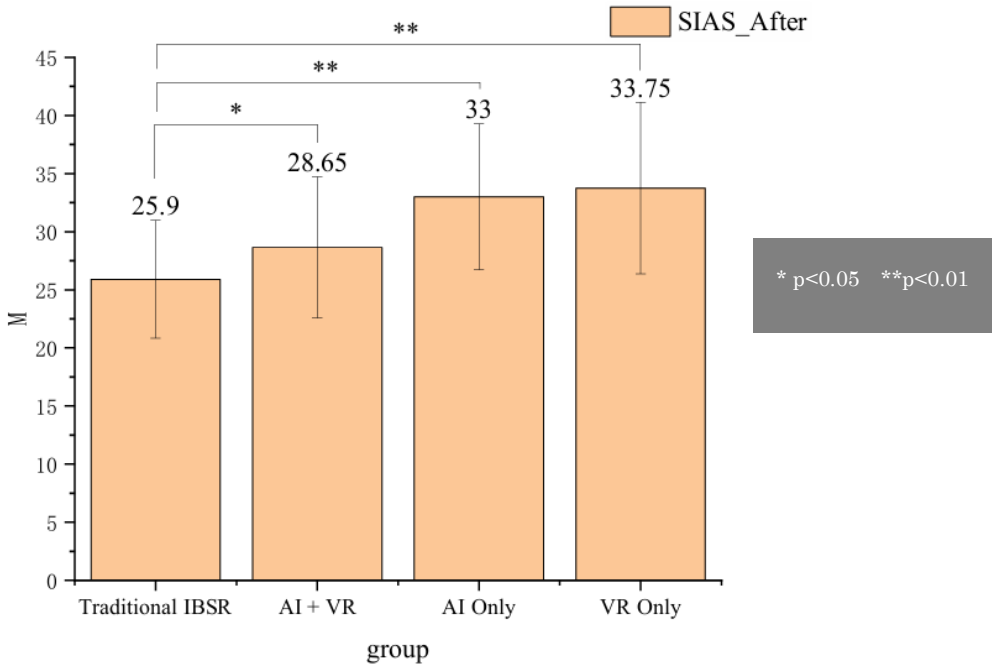

Table 6 Post-Intervention SIAS Scores by Group with Significant Between-Group Differences

intervention outcomes.

As visualized in Table 6, the AI + VR group occupies a middle position—outperformed by human-facilitated IBSR but clearly superior to single-modality approaches. These findings suggest that the combination of AI and VR is not merely additive but rather involves a deeper integration mechanism where cognitive restructuring and emotional resonance are tightly coupled.

Further interpretation reveals two key insights. First, the traditional human-guided method continues to demonstrate a steep decline in anxiety levels, likely owing to its structured logic and therapeutic alliance. Second, the hybrid AI + VR system shows significant promise, not through mere technological layering, but through its ability to coordinate introspective dialogue with sensory immersion—offering a more embodied and meaningful processing experience than AI or VR alone.

Overall, these results strongly support the core hypothesis of the study: that multi-modal interventions offer greater therapeutic benefit than single-modality systems. They also confirm that while traditional methods remain most effective in the short term, AI + VR integration presents a viable and scalable alternative for belief-based cognitive therapy in digital environments.

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4.3 One-Week Post-Intervention Comparison

To further examine the short-term persistence of intervention effects, all participants completed a follow-up assessment using the Social Interaction Anxiety Scale (SIAS) seven days after their initial intervention. A one-way ANOVA revealed highly significant differences in SIAS_one week scores across the four intervention groups ($F = 8.904$, $p < 0.001$), indicating that the effectiveness of each intervention method remained distinct even one week after treatment.

3. One-Week Follow-Up Comparison

ANOVA Results

Group (Mean ± SD)	AI + VR (n = 20)	AI Only (n = 20)	Traditional IBSR (n = 20)	VR Only (n = 20)	F	p
SIAS_OneWeek	29.650 ± 6.532	34.200 ± 6.461	26.050 ± 4.774	35.450 ± 7.763	8.904	0.000 ***

- $p < .1$ ** $p < .05$ *** $p < .01$

Table 7 One-Week Follow-Up Comparison

Table 7 presents the mean and standard deviation of SIAS scores for each group at the one-week mark. The Traditional IBSR group showed the lowest average score ($M = 26.05$), outperforming all other groups significantly. This result highlights the lasting therapeutic benefit of traditional, facilitator-led cognitive inquiry, which maintained its advantage not only in immediate evaluations but also in sustained follow-up.

The AI + VR group followed with an average score of 29.65, significantly lower than both the AI Only group (34.20) and the VR Only group (35.45). These findings support the synergistic advantage of combining AI-driven belief inquiry with immersive VR environments, suggesting that multi-modal integration enhances intervention durability more effectively than single-modality designs.

Interestingly, there was no statistically significant difference between the AI Only and VR Only groups, indicating that while each modality may provide short-term relief, neither is sufficient on its own to drive durable cognitive transformation. For conditions like social anxiety—which involve both emotional and belief-based components—simple exposure or scripted interaction lacks the depth necessary to

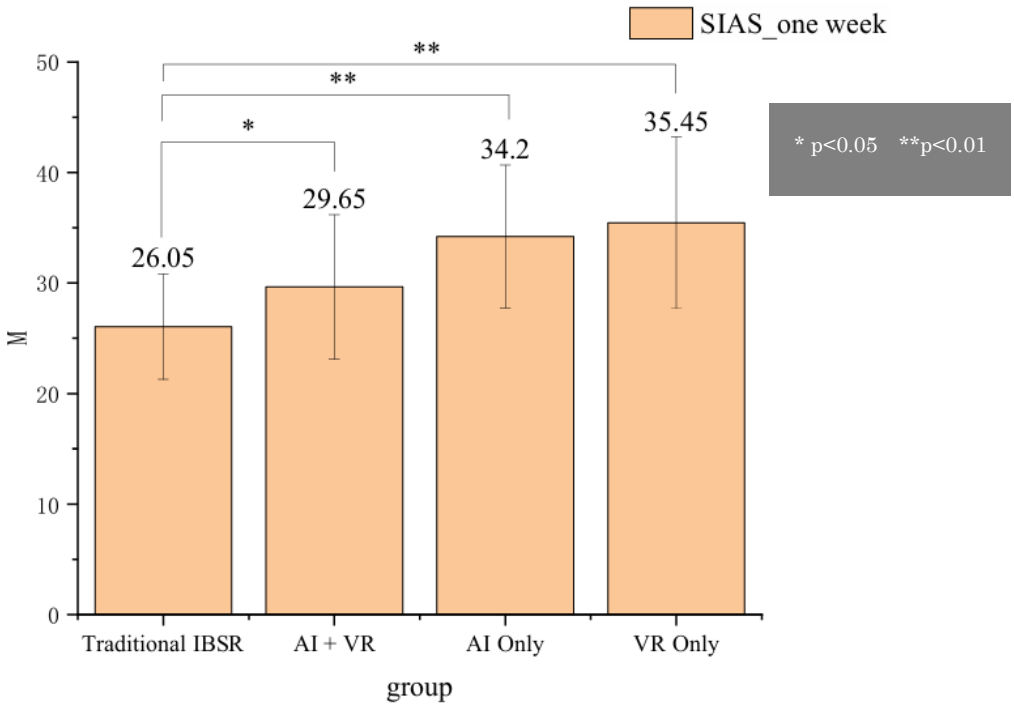

Table 8 One-Week Follow-Up SIAS Scores by Group with Significant Between-Group Differences

produce lasting change.

Table 8 provides a visual representation of these one-week SIAS scores and their statistical differences. The chart clearly illustrates the superior performance of the Traditional IBSR group, followed by the AI + VR group. The relative ineffectiveness of the AI Only and VR Only groups is also apparent, further emphasizing that technological interventions must be designed to support deep cognitive restructuring rather than surface-level interaction or passive exposure.

In summary, traditional IBSR demonstrated the strongest sustained reduction in social anxiety, while the AI + VR hybrid approach showed promising short-term benefits through its integration of cognitive inquiry and emotional immersion. In contrast, the standalone AI and VR conditions produced minimal lasting change, highlighting the limitations of single-path interventions and underscoring the importance of systemic cognitive design in digital mental health tools.

4.4 Within-Group Comparisons of Single-Factor Variance

4. Within-Group Comparisons Using One-Way ANOVA

ANOVA Results

Group	SIAS_Before (n = 20)	SIAS_After (n = 20)	SIAS_OneWeek (n = 20)	F	p
Traditional IBSR	40.200 ± 6.526	25.900 ± 5.057	26.050 ± 4.774	44.503	0.000 ***
AI + VR	38.400 ± 7.141	28.650 ± 6.063	29.650 ± 6.532	13.237	0.000 ***
AI Only	38.200 ± 6.510	33.000 ± 6.274	34.200 ± 6.461	3.602	0.034 **
VR Only	39.900 ± 8.058	33.750 ± 7.369	35.450 ± 7.763	3.371	0.041 **

- $p < .1$ ** $p < .05$ *** $p < .01$

Table 9 Within-Group Comparisons Using One-Way ANOVA

To further explore the time-based effects of different intervention formats, a within-group one-way ANOVA was conducted for each experimental group across the three time points: pre-intervention (SIAS_Before), post-intervention (SIAS_After), and one-week follow-up (SIAS_one week). **Table 9** presents the descriptive statistics for each group, while **Table 10** visualizes the longitudinal changes in social interaction anxiety (SIAS scores) across time.

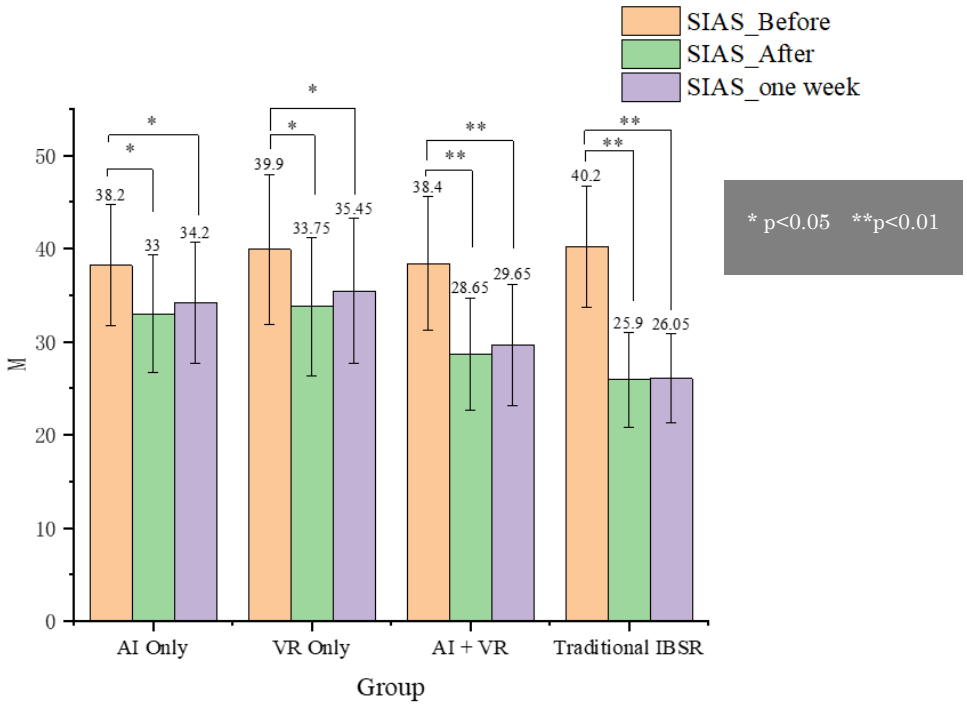

Table 10 Pre-, Post-, and One-Week Follow-Up SIAS Scores by Intervention Group

In the Traditional IBSR group, participants showed a sharp and statistically significant reduction in social anxiety, with SIAS scores dropping from 40.20 at baseline to 25.90 immediately after the intervention and remaining stable at 26.05 one week later. The within-group variance was highly significant ($F = 44.503$, $p < 0.001$), indicating not only immediate but also lasting effects. As illustrated in **Table 10**, the group exhibited the steepest and most sustained decline, reinforcing the strength of structured, therapist-led cognitive interventions.

The AI + VR hybrid group also demonstrated significant improvement, with SIAS scores decreasing from 38.40 to 28.65 after the intervention and stabilizing at

29.65 after one week. The within-group analysis yielded $F = 13.237$ ($p < 0.001$), confirming that the combined use of AI-driven inquiry and immersive VR environments effectively supported emotional and cognitive processing. Although not as powerful as the traditional format, the hybrid approach showed robust therapeutic value.

In contrast, the AI Only and VR Only groups experienced more modest changes. The AI Only group's SIAS scores reduced from 38.20 to 33.00, then slightly rebounded to 34.20 after a week ($F = 3.602$, $p = 0.034$). Similarly, the VR Only group's scores went from 39.90 to 33.75, and then increased to 35.45 ($F = 3.371$, $p = 0.041$). These patterns suggest that while both single-technology interventions had some positive effect, the impact was limited and less stable over time.

As shown in **Table 10**, all groups displayed a post-intervention drop in anxiety, but the slope and persistence of improvement varied. The Traditional IBSR group maintained the most significant and consistent gains, followed by the AI + VR group, which demonstrated the most promising potential among the tech-based formats. In contrast, the AI Only and VR Only groups showed higher rebound trends, indicating insufficient depth in cognitive restructuring.

In summary, the within-group comparisons underscore the differential strength and sustainability of the interventions. Traditional IBSR yielded the most durable

outcomes, while the AI + VR format showed notable promise for digital therapy. On the other hand, single-modality approaches—AI Only and VR Only—provided limited short-term benefit but lacked the structure to support long-lasting transformation.

4.5 Group Comparison of Improvement Scores

To further examine differences in the strength and sustainability of intervention outcomes, this section introduces two derived indicators. Improvement1 captures the immediate treatment effect, defined as the difference between pre-test and post-test SIAS scores (SIAS_Before – SIAS_After). Improvement2, on the other hand, measures short-term retention of therapeutic benefit, calculated as the difference between post-test and one-week follow-up scores (SIAS_After – SIAS_OneWeek).

Group (Mean ± SD)	AI + VR (n = 20)	AI Only (n = 20)	Traditional IBSR (n = 20)	VR Only (n = 20)	F	p
Improvement1 (Before → After)	9.750 ± 3.110	5.200 ± 2.142	14.300 ± 3.868	6.150 ± 1.981	41.136	0.000 ***
Improvement2 (After → 1 Week)	-1.000 ± 1.376	-1.200 ± 2.687	-0.150 ± 0.875	-1.700 ± 2.473	2.087	0.109

- $p < .1$ ** $p < .05$ *** $p < .01$

Table 11 Comparison of Change Scores

As shown in **Table 11**, significant group differences emerged in Improvement1 scores ($F = 41.136$, $p < 0.001$). The Traditional IBSR group exhibited the most substantial reduction in social anxiety symptoms, with an average improvement of 14.30 points—markedly higher than all other groups. This reinforces the well-established efficacy of structured, in-person cognitive interventions in generating rapid, deep shifts in anxiety-related cognition.

The AI + VR group achieved the second-highest improvement ($M = 9.75$), reflecting the synergistic benefit of combining AI-guided inquiry with immersive VR environments. This hybrid design leverages both cognitive reappraisal through dialogue and emotional activation through virtual scene metaphors. It offers users a more complete and engaging therapeutic journey than either modality alone.

In contrast, the AI Only ($M = 5.20$) and VR Only ($M = 6.15$) groups showed significantly smaller gains. While still beneficial, these results suggest that single-mode interventions may lack either the emotional depth (in the case of AI Only) or the cognitive restructuring mechanisms (in the case of VR Only) required to produce large-scale improvement in social anxiety symptoms.

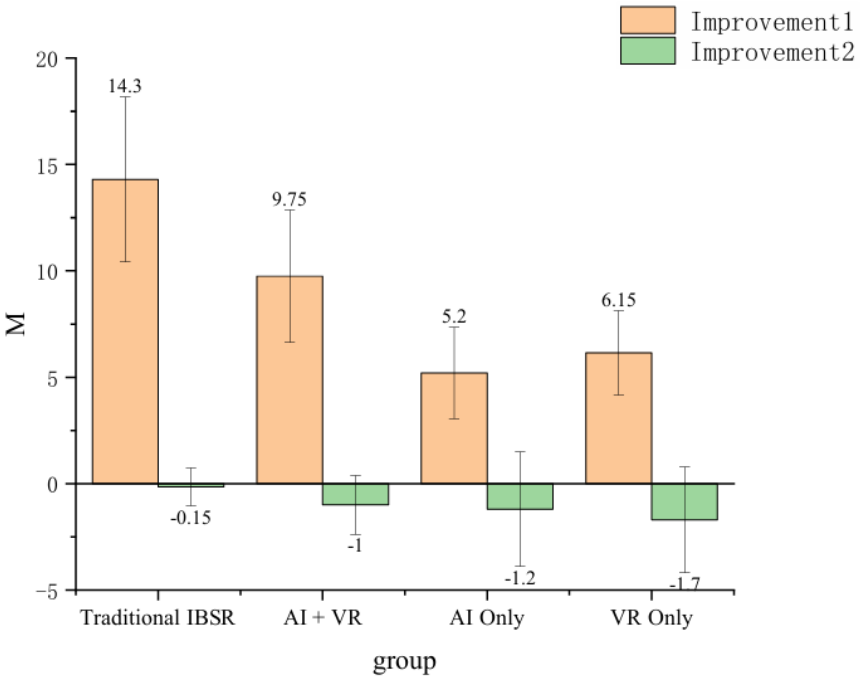

Table 12 SIAS Score Improvements Across Time Points

Table 12 illustrates group differences in Improvement2—how much change occurred between the post-test and the one-week follow-up. Although the group difference was not statistically significant ($F = 2.087$, $p = 0.109$), the trends were nonetheless informative. The VR Only group demonstrated the largest average regression (-1.70), suggesting that while VR scenarios may offer immediate relief, their therapeutic effects may diminish quickly without cognitive reinforcement. The AI Only group also showed notable regression (-1.20), implying that dialogue alone might be insufficient to sustain emotional gains over time.

The AI + VR group demonstrated slightly better retention (-1.00), pointing to the

stabilizing effect of integrating modalities. However, the Traditional IBSR group once again stood out for its durability: the mean regression was only -0.15, indicating that participants were able to maintain most of the benefits gained during intervention. This underscores the depth and lasting impact of traditional cognitive work, likely supported by structured emotional processing and personal reflection.

In summary, the Traditional IBSR method outperformed all other groups in both immediate and short-term outcomes. The AI + VR group showed promising potential, significantly outperforming the AI Only and VR Only groups in immediate gains and retaining more benefits over time. These findings suggest that integrating AI and VR technologies into therapeutic workflows can be effective, but they must be carefully designed to mimic the cognitive depth and emotional engagement found in traditional human-facilitated methods.

4.6 Chi-Square Analysis of Clinical Anxiety Remission

To further evaluate the clinical significance of each intervention method in alleviating social anxiety, this study adopted a standardized classification approach based on validated literature. A score on the Social Interaction Anxiety Scale (SIAS) greater than or equal to 36 was defined as indicating the presence of clinical anxiety

("yes"), whereas a score below 36 was considered to indicate no clinical anxiety ("no") [35]. This binary classification was applied consistently across all three assessment points: pre-intervention, immediate post-intervention, and seven-day follow-up.

At the baseline stage, there was no statistically significant difference in the distribution of anxiety states across the four experimental groups ($\chi^2 = 0.615$, $p = 0.893$), suggesting that the groups were well-balanced and comparable in terms of initial psychological state.

6. Cross-tabulation (Chi-Square Analysis Results)

Chi-Square Analysis Results

Item	Label	Group(%)				Total(%)	χ^2	*p*
		AI + VR	AI Only	Traditional IBSR	VR Only			
SIAS_Before	no	7(35.00)	6(30.00)	6(30.00)	8(40.00)	27(33.75)		
	yes	13(65.00)	14(70.00)	14(70.00)	12(60.00)	53(66.25)	0.615	0.893
Total(%)		20	20	20	20	80		
SIAS_After	no	17(85.00)	15(75.00)	20(100.00)	11(55.00)	63(78.75)		
	yes	3(15.00)	5(25.00)	0(0.00)	9(45.00)	17(21.25)	12.773	0.005**
Total(%)		20	20	20	20	80		
SIAS_one week	no	17(85.00)	12(60.00)	20(100.00)	10(50.00)	59(73.75)		
	yes	3(15.00)	8(40.00)	0(0.00)	10(50.00)	21(26.25)	16.207	0.001**
Total(%)		20	20	20	20	80		

* $p<0.05$ ** $p<0.01$

Table 13 Cross-Tabulation (Chi-Square) Analysis Results

However, significant differences emerged in the post-intervention and follow-up phases. As shown in **Table 13**, the association between intervention type and clinical anxiety status was statistically significant at both time points (Immediate Post-Intervention: $\chi^2 = 12.773$, $p = 0.005$; Seven-Day Follow-Up: $\chi^2 = 16.207$, $p = 0.001$).

The traditional IBSR group demonstrated the most notable clinical effect. At

both assessment points, all participants in this group scored below 36, indicating a 100% clinical remission rate that was both strong and stable over time.

The AI + VR group also showed promising results. At the immediate post-intervention checkpoint, 85% of participants were classified as no longer clinically anxious. Even after seven days, over 80% maintained scores below the anxiety threshold, reflecting the short-term effectiveness and sustainability of this integrated technological intervention.

In contrast, the AI Only and VR Only groups exhibited more limited effects. While the AI Only group had 75% of participants fall below the threshold immediately after intervention, this dropped to 60% after one week. The VR Only group had the lowest performance, with only 55% in remission post-intervention and 50% at follow-up, indicating both weaker effect magnitude and poor persistence.

In summary, the traditional IBSR approach remained the most effective in terms of clinical anxiety remission. The AI + VR hybrid model showed substantial potential as a scalable, tech-enabled intervention, whereas single-technology approaches (AI Only or VR Only) appeared to lack sufficient depth or system integration to deliver and sustain meaningful psychological change.

Table 13 summarizes the clinical anxiety classification outcomes across the three time points for all four groups, providing a critical reference for evaluating the

clinical relevance of multi-modal intervention strategies.

4.7 Gender Differences in Clinical Response Pattern

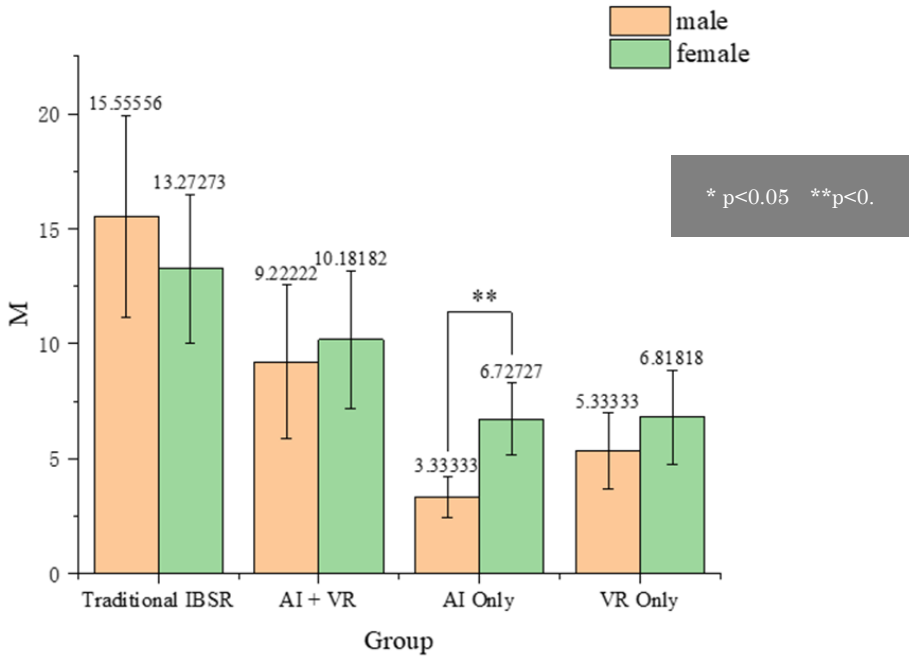

Table 14 Gender-Based Comparison of SIAS Score Reduction (Before-After) in Each Group

To investigate gender-based differences in the clinical effects of the four intervention modalities, we analyzed the pre- to post-intervention (Before–After) improvements in SIAS (Social Interaction Anxiety Scale) scores for male and female participants. It is important to note that the data in **Table 14** is derived exclusively from the immediate improvement between the pre- and post-intervention assessments, and does not include results from the one-week follow-up. As the difference between immediate post-intervention and one-week scores was minimal, only the immediate treatment effects are

examined here.

In the Traditional IBSR group, male participants showed an average improvement of 15.556 points, slightly higher than the 13.273-point improvement among females. This suggests that the human-facilitated intervention was effective for both genders, with males potentially responding more favorably in this structured therapeutic context. In contrast, the AI + VR group showed more balanced yet female-leaning results, with females improving by an average of 10.182 points compared to 9.222 for males.

Larger gender disparities emerged in the AI Only and VR Only groups. In the AI Only condition, female participants improved by an average of 6.727 points, while males improved by only 3.333—less than half the female outcome. Similarly, in the VR Only group, females improved by 6.818 points compared to 5.333 for males. These patterns suggest that female participants may derive greater therapeutic benefit from immersive digital interventions, particularly in the absence of human facilitation.

Taken together, these findings underscore the importance of incorporating gender as a moderating factor in treatment evaluation. While Traditional IBSR continues to demonstrate robust efficacy across genders, AI- and VR-based interventions appear especially beneficial for female users. One possible explanation is that women may feel less inhibited when interacting with non-human systems, such as AI or VR, which allow for greater emotional privacy and self-disclosure. In contrast, traditional face-to-face

settings may induce reluctance to share due to social stigma or fear of judgment. This insight highlights the potential of digitally facilitated systems like AI + VR to close the gender gap in clinical treatment responsiveness.

4.7.1 Gender Differences in Social Anxiety Outcomes

The observed pattern aligns with a growing body of research suggesting that women often report higher baseline social anxiety and are more responsive to structured therapeutic interventions [36][37][38]. This may reflect a larger symptom margin for measurable improvement post-intervention [39][40].

One key explanatory factor lies in gender-specific cognitive-emotional processing styles. Women are more likely to experience fear of negative evaluation, internalized shame, and social withdrawal, which are all central to the manifestation of Social Anxiety Disorder (SAD) [41][42]. These traits increase their receptiveness to introspective and emotionally engaging interventions—especially those structured through AI-guided dialogue or immersive VR environments [43][44].

Women also tend to exhibit higher levels of verbal emotional expression and self-reflective thinking, which align well with the narrative-driven and inquiry-based frameworks of IBSR systems, regardless of whether they are delivered through human, AI, or VR formats [45][46].

Beyond psychological mechanisms, biological and psychosocial factors also contribute to gendered treatment responses. Hormonal fluctuations—particularly in estrogen and progesterone—have been shown to modulate emotional regulation and anxiety symptoms. Women are also more likely to present with comorbid conditions such as depression or panic disorder, which, although complicating the clinical profile, may simultaneously enhance treatment engagement and motivation [47].

Epidemiological data further contextualize these differences: SAD has a lifetime prevalence of 13.3%, with 15.5% in women and 11.1% in men. Despite higher prevalence among females, men are reportedly more likely to seek formal treatment. These gendered trends may be shaped by cultural norms around emotional disclosure and stigma. Importantly, hormonal changes—such as during pregnancy or oral contraceptive use—can also influence anxiety trajectories. SAD in women is often complicated by additional risks (e.g., depression, substance use), which, if left untreated, may also impact fetal health. Therefore, treatment plans should integrate gender-specific variables, including hormone status and psychiatric comorbidity, when tailoring interventions.

In conclusion, gender is a critical moderator of treatment efficacy. AI- and VR-based therapeutic systems could benefit from incorporating gender-sensitive features, such as adaptive emotional modeling, personalized pacing, and tailored language

processing, to optimize effectiveness across user profiles and bridge the gender gap in digital mental health care.

Chapter 5 Discussion and Future Work

5.1 Interpretation of Key Findings

This study systematically compared the effectiveness of four intervention modalities—Traditional IBSR, AI Only, VR Only, and the combined AI + VR approach—in reducing symptoms of social anxiety. By tracking changes in SIAS (Social Interaction Anxiety Scale) scores across three time points (pre-intervention, immediately post-intervention, and one-week follow-up), as well as evaluating clinical remission based on a validated SIAS threshold, several key findings emerged that offer both theoretical insight and practical implications.

One of the most prominent findings is the significant effect of intervention type on treatment outcomes. The Traditional IBSR group consistently demonstrated the greatest reduction in SIAS scores across all time points and achieved the highest rate of clinical remission. All participants in this group fell below the clinical anxiety threshold one week after the intervention, confirming the long-standing efficacy of structured, face-to-

face cognitive interventions. These results underscore the enduring value of human-guided therapeutic methods in facilitating deep cognitive restructuring and emotional processing.

The AI + VR group also demonstrated robust therapeutic effects. Participants in this group showed a significant decrease in SIAS scores, with over 85% maintaining non-anxious status one week post-intervention. These findings suggest that the integration of AI-guided dialogue and immersive VR environments can replicate many of the cognitive and emotional mechanisms found in traditional interventions. The AI + VR system thus emerges as a promising model for scalable, technology-driven mental health solutions that maintain both depth and engagement.

In contrast, the AI Only and VR Only groups showed more modest improvements. The AI Only group, which focused solely on verbal interactions, lacked emotional immersion, while the VR Only group, though immersive, did not offer structured cognitive guidance. Both groups exhibited smaller reductions in anxiety scores and lower clinical remission rates at follow-up. These results highlight the limitations of single-modality interventions and the importance of combining emotional immersion with structured introspective frameworks.

Gender was also found to be a significant moderator in treatment response. Across all conditions, female participants exhibited greater average improvement than male participants. This gender disparity was especially pronounced in the AI + VR condition, where females showed both larger score reductions and higher rates of transitioning from anxious to non-anxious status. These findings suggest that women may be more receptive to digital interventions, particularly those offering emotional privacy and self-paced engagement.

Interestingly, in the Traditional IBSR group, male participants exhibited slightly greater average score improvements than females, suggesting that male participants may respond more favorably in direct human-guided settings. Conversely, in the AI Only and VR Only groups, females demonstrated significantly greater gains, potentially due to higher comfort with self-disclosure in non-human interactions and greater verbal-emotional fluency.

Finally, by converting SIAS scores into binary clinical categories (anxious vs. non-anxious), the study further confirmed that the interventions resulted in not only statistically significant score reductions but also clinically meaningful improvements. Chi-square tests showed that both the Traditional IBSR and AI + VR groups achieved significantly higher rates of clinical anxiety remission compared to the AI Only and VR Only groups, both immediately and one week after the intervention.

In summary, the findings indicate that intervention structure, degree of technological integration, and participant gender interact in complex ways to shape treatment outcomes. While Traditional IBSR continues to set the benchmark for clinical effectiveness, AI + VR demonstrates the most potential among digital formats, particularly for female users. With further optimization in cognitive design and emotional scaffolding, AI + VR could serve as a highly scalable and effective tool in the digital mental health landscape.

5.2 Comparison with Prior Studies

The findings of this study resonate with prior research that underscores the high prevalence and clinical burden of Social Anxiety Disorder (SAD) globally, particularly among youth and young adults. Previous studies have consistently identified cognitive distortions, negative self-evaluation, and avoidance behavior as core features of SAD, and have demonstrated the effectiveness of therapies such as Cognitive Behavioral Therapy (CBT), exposure therapy, and mindfulness-based approaches in reducing these symptoms [1][3][5]. Inquiry-Based Stress Reduction (IBSR), as a structured cognitive method centered on introspective questioning, has also shown promising results in alleviating stress, anxiety, and burnout, especially in

educational or non-clinical populations [8][9][10].

However, this study significantly diverges from earlier work in both its methodological approach and its technological application. Most notably, while previous studies have treated IBSR as a human-facilitated or paper-based intervention, the present study is among the first to systematically compare IBSR across multiple delivery modalities, including human-facilitated sessions, AI-guided digital dialogues, VR-based immersive content, and a combined AI + VR format. This consistent use of IBSR across all intervention conditions establishes a unique framework in which the modality—not the therapeutic method—is the independent variable.

Another key departure from previous research lies in the integration of technological platforms not merely as presentation tools, but as dynamic vehicles for cognitive inquiry. In prior work involving AI or VR in mental health, the systems were often designed for guided relaxation, psychoeducation, or basic behavioral exposure [15][16][17]. In contrast, the AI and VR modules in this study were specifically adapted to replicate the structured logic and reflective depth of IBSR, offering users a cognitively engaging and emotionally responsive environment for internal processing. This design choice bridges the gap between passive digital support and active cognitive restructuring.

Moreover, the study contributes new empirical evidence on the relative efficacy of digitally delivered IBSR. The AI + VR condition, in particular, demonstrated clinical outcomes that closely approximated those of the traditional human-guided format, especially for female participants. This finding is especially relevant given the ongoing shortage of trained mental health professionals in many regions. Previous research has seldom addressed whether IBSR—when delivered via non-human agents—can maintain its therapeutic effectiveness. The present study provides early evidence that a well-designed multimodal system can indeed function as a cost-effective and scalable alternative to therapist-led interventions, without sacrificing efficacy.

In addition to its technological contributions, this study also offers a novel lens on gender-specific responses to intervention. While previous literature has documented that women often exhibit higher baseline anxiety and greater responsiveness to therapy, few studies have explored how these gender dynamics manifest in the context of digital IBSR delivery [36][38][41]. The observed pattern—that women benefited more from AI and VR-based formats—suggests that digital systems may offer a lower-stigma, emotionally safer space for certain users to engage in therapeutic reflection, particularly those who might hesitate to disclose personal vulnerabilities in face-to-face sessions.

Finally, unlike many prior studies that limit evaluation to immediate pre- and post-treatment snapshots, this research includes three time points: baseline, immediate post-intervention, and one-week follow-up. Although the one-week post-test results showed minimal variance from immediate outcomes and were not used in certain analyses (such as Table 14), the inclusion of this intermediate measure offers stronger temporal resolution than single-session designs, allowing for a more informed understanding of short-term treatment sustainability.

In summary, this study not only replicates earlier findings regarding the utility of IBSR and the potential of digital mental health tools, but also extends the field by demonstrating how a single therapeutic framework can be flexibly deployed across human and non-human interfaces. It reveals that digitally enabled IBSR—especially in AI + VR configurations—holds promise as an accessible, lower-cost adjunct or alternative to traditional therapy, while also uncovering important gender-based nuances in clinical responsiveness. These innovations position the study at the intersection of cognitive intervention theory and applied digital mental health, offering a blueprint for future work in technologically mediated psychological care.

5.3 Implications for Digital Mental Health Tools

The findings of this study carry several important implications for the design, scalability, and personalization of digital mental health tools, particularly those intended to address Social Anxiety Disorder (SAD).

First and foremost, this study demonstrates that digital implementations of structured interventions such as Inquiry-Based Stress Reduction (IBSR) can achieve clinically meaningful results when carefully adapted into immersive or interactive formats. The comparable effectiveness between the traditional IBSR group and the AI + VR group suggests that, with appropriate design logic and emotional scaffolding, technology-driven platforms can reproduce much of the therapeutic value of human-facilitated sessions. This finding offers a critical path forward for expanding access to high-quality mental health interventions, especially in contexts where professional therapists are scarce or inaccessible due to cost, geography, or social stigma.

Second, this study highlights the importance of modality matching in digital therapy. While all four intervention groups shared a common theoretical foundation—IBSR—their therapeutic outcomes varied substantially depending on the delivery medium. Notably, the AI + VR condition not only closely approximated the efficacy of traditional human facilitation, but also exhibited unique advantages in specific user groups, such as female participants. This suggests that the combination of structured dialogue (via AI)

and emotional immersion (via VR) may offer an optimal balance between cognitive engagement and emotional safety, particularly for individuals who may be less comfortable with face-to-face disclosure.

Moreover, the data support the notion that technological interventions can be customized to fit different psychological profiles. For instance, the relatively lower performance of male participants in AI and VR-only conditions points to the potential benefit of incorporating adaptive features—such as gender-sensitive dialogue strategies, paced reflection, or dynamic feedback algorithms—to better accommodate diverse cognitive-emotional processing styles. This aligns with emerging literature advocating for intelligent personalization in digital mental health platforms [16][20][45].

Importantly, this study repositions IBSR as a versatile framework that can be delivered beyond the conventional therapeutic setting. Previous applications of IBSR have primarily relied on human-facilitated introspection; here, its structure was successfully encoded into AI scripts and VR sequences, effectively transforming it into a scalable software-based intervention. This technological shift not only enhances accessibility but also opens new possibilities for integration into educational, corporate, or remote clinical environments.

Additionally, by achieving similar clinical outcomes using fewer human resources, digital adaptations of IBSR—particularly the AI + VR system—offer strong potential for

cost-effective implementation in large-scale mental health initiatives. This is particularly relevant for public health systems and institutions operating under financial or logistical constraints, as the need for scalable, yet evidence-based mental health solutions continues to grow globally.

Finally, the results contribute to the broader discourse on digital trust and therapeutic authenticity. The positive outcomes observed in technology-mediated conditions suggest that, under certain circumstances, users may perceive AI or VR not as impersonal tools but as psychologically “safe” spaces. This challenges traditional assumptions about the superiority of human contact in therapy and raises important questions about how digital systems can cultivate therapeutic alliance, emotional regulation, and user trust.

In summary, the integration of IBSR with AI and VR technologies offers a promising direction for the future of digital mental health care. The success of the hybrid system demonstrated in this study supports a paradigm shift—from viewing digital tools merely as supplements to human therapy, toward recognizing them as autonomous or semi-autonomous therapeutic modalities with unique strengths and applications.

5.4 Limitations of This Study

While this study provides promising insights into the potential of technology-

integrated IBSR interventions for alleviating social anxiety, several limitations must be acknowledged to contextualize the findings and guide future research.

One primary limitation lies in the sample composition. The participant pool consisted predominantly of young adults from university settings, which may limit the generalizability of the results to broader or more diverse populations such as adolescents, older adults, or clinical patients with comorbid disorders. Given that social anxiety manifests differently across life stages and cultural backgrounds, future studies should strive for more heterogeneous samples.

Second, the study's intervention period was relatively short. Although immediate and one-week post-intervention assessments were conducted, long-term efficacy and relapse rates remain unexplored. Social anxiety often exhibits chronic characteristics, and a single-session or brief intervention may not fully reflect the durability of treatment outcomes. Incorporating longitudinal follow-ups over months or even years would provide a more comprehensive understanding of therapeutic sustainability.

Third, while the study introduced a novel integration of AI and VR technologies, the AI dialogue system was based on pre-programmed scripts rather than adaptive natural language processing. This limited the system’s ability to dynamically respond to participants' emotional or cognitive states in real time. Although this design ensured consistency across sessions, it may have constrained the depth of

personalized engagement.

Another methodological limitation involves the reliance on self-report measures, particularly the SIAS scale. Although widely validated, self-reports are susceptible to social desirability bias and subjective perception. Future studies could benefit from incorporating physiological indicators (e.g., heart rate variability, skin conductance) or behavioral observations to triangulate self-reported outcomes.

Moreover, the absence of a placebo or waitlist control group limits the ability to attribute observed effects solely to the active components of each intervention. Without such a baseline comparator, it remains unclear whether improvements resulted from the IBSR structure, the novelty of the technology, or a combination of both.

Finally, while gender-based differences were observed and analyzed, other important moderating variables such as personality traits, previous therapy history, or digital literacy were not fully examined. These factors may influence both the engagement with and the efficacy of AI- and VR-based interventions.

Despite these limitations, the current study serves as a foundational step in understanding how IBSR can be technologically adapted and scaled. Acknowledging these constraints is crucial for refining future experimental designs and enhancing the clinical utility of digital mental health tools.

5.5 Recommendations for Future Research

Building on the findings and limitations of this study, several avenues are recommended for future research to advance the development and application of digitally delivered IBSR (Inquiry-Based Stress Reduction) interventions.

One key direction is the adoption of longitudinal experimental designs. This study focused primarily on short-term effects—immediate and one-week post-intervention. However, social anxiety is a persistent condition with high recurrence rates, and short-term improvements may not reflect long-term efficacy. Future studies should consider adding longer follow-up intervals (e.g., one month, three months, six months) to assess sustained symptom remission and determine whether digital interventions such as AI + VR maintain their benefits over time.

Second, participant diversity should be expanded. The current sample consisted predominantly of university students, which improves internal validity but limits generalizability. Future research should include more varied populations, such as working adults, adolescents, older adults, and high-risk groups (e.g., individuals with a history of anxiety or depression, pregnant women, or socially marginalized populations) to enhance external validity.

Third, there is a strong rationale to integrate real-time emotion detection and adaptive feedback. The AI and VR systems used in this study operated on fixed scripts

and did not dynamically adjust based on users' real-time emotional states. Future systems could benefit from incorporating multimodal emotion recognition technologies—such as speech prosody analysis, facial expression detection, eye tracking, or physiological signals like heart rate or skin conductance. This would enable personalized pacing and emotionally congruent feedback, increasing both therapeutic resonance and user engagement.

Fourth, gender differences emerged as a critical moderating factor in treatment response. This study revealed that female participants generally showed greater improvements than males, particularly in AI and VR interventions. Future work should further explore the underlying mechanisms—such as differences in cognitive-affective processing, social stigma, help-seeking behavior, and hormonal influences (e.g., estrogen fluctuations)—that may account for this disparity. Researchers should consider stratifying analyses by gender or employing interaction models to better understand how intervention format interacts with gender to influence outcomes. Moreover, digital systems should be optimized with gender-responsive features, such as emotionally validating language, adaptive narrative framing, and customizable pacing to support varying engagement styles.

Fifth, future research should focus on building adaptive, context-sensitive AI and VR dialogue engines. While the IBSR framework was successfully transferred into AI

and VR formats, the current conversational logic remains relatively static. Advancements in natural language processing and large language models may allow future systems to generate dynamic, semantically coherent responses tailored to user input, emotional state, and cognitive load. This could facilitate deeper cognitive restructuring and more authentic user introspection.

Lastly, future studies would benefit from mixed-methods research designs. While quantitative outcomes are essential for measuring efficacy, qualitative insights—such as user narratives, emotional logs, and interviews—can uncover hidden dimensions like trust, emotional safety, immersion, and stigma. These qualitative data would provide a more holistic understanding of user experience, especially in populations that may find digital interventions less intuitive or more emotionally challenging.

In summary, future research on digital IBSR systems should aim for broader temporal coverage, participant diversity, emotional intelligence integration, gender-based optimization, and methodological richness. Special attention to gender-specific pathways and technological tailoring will be crucial for scaling digital mental health tools to a wider, more diverse population while maintaining both efficacy and inclusiveness.

Chapter 6 Conclusion

6.1 Summary of Contributions

This study presents several original contributions to the field of digital mental health, particularly in the context of social anxiety intervention through digital adaptations of Inquiry-Based Stress Reduction (IBSR). Unlike prior research, which has predominantly treated IBSR as a human-facilitated, introspective therapeutic process, this study systematically examines and compares four distinct delivery modes: traditional therapist-led IBSR, AI-guided IBSR, VR-facilitated IBSR, and a combined AI + VR hybrid system. By empirically evaluating each condition in a controlled experimental design, the study fills a critical gap in the literature on how reflective, inquiry-based interventions can be digitized.

To be clear, this research does not seek to replace the traditional human-led IBSR format, which remains the most authoritative and mature delivery method for this deeply dialogic and personalized intervention. Rather, it attempts to approximate its therapeutic depth through an integrative use of artificial intelligence and immersive media. Results show that the AI + VR hybrid system—which combines semantic guidance with emotionally evocative visual immersion—achieves clinical improvement levels that approach those of traditional therapy in some outcome

measures, especially in reducing symptoms of social anxiety.

A major contribution of this study is its explicit focus on accessibility, which served as a central research problem from the outset. Individuals with social anxiety often avoid traditional therapy due to fear of judgment, logistical challenges, or limited availability of trained professionals. This research addresses that gap by developing a scalable, low-cost, privacy-preserving system that requires no in-person contact and can operate autonomously on local devices. By combining AI-driven dialogue and VR-driven emotion regulation, the system aims to offer an approachable, repeatable, and stigma-reducing alternative that lowers the threshold for therapeutic entry.

Another contribution lies in the exploration of gender-based differences in treatment responsiveness. The study finds that female participants tended to benefit more from digital interventions, possibly due to higher baseline anxiety levels or more verbal-emotional introspection styles. This insight advances theoretical understanding of user-specific mechanisms and underscores the importance of personalized design in digital mental health tools.

Beyond average group-level improvements, the study also applies clinical significance metrics, such as the proportion of participants who moved from "anxious" to "non-anxious" status based on the SIAS scale. This dual approach—

combining statistical and clinical evaluation—strengthens the real-world applicability of the findings.

Finally, the study offers a replicable methodological framework for translating psychological theories into working digital systems. By combining cognitive-behavioral principles, AI-based language modeling, and VR scene design, it demonstrates how traditionally introspective therapies like IBSR can be reimagined through human-computer interaction. This integrated pipeline serves as a blueprint for future research and development in AI-augmented mental health care.

In sum, the value of this research lies not in displacing traditional methods, but in expanding their reach. It proposes a technology-assisted supplement to authoritative human-led interventions—one that aims to balance therapeutic depth with accessibility, scalability, and user autonomy. This work contributes a viable pathway toward making high-quality cognitive interventions available to broader, underserved populations in the digital age.

References

[1] Suhas, Satish, et al. "Nationally representative epidemiological study of social anxiety disorder from India." *Indian Journal of Psychiatry* 65.12 (2023): 1261-1268.

[2] Emmelkamp, Paul MG, Katharina Meyerbröker, and Nexhmedin Morina. "Virtual reality therapy in social anxiety disorder." *Current psychiatry reports* 22.7 (2020): 32.

[3] Stein, Murray B., and Dan J. Stein. "Social anxiety disorder." *The lancet* 371.9618 (2008): 1115-1125.

[4] Buist-Bouwman, M. A., et al. "Functional disability of mental disorders and comparison with physical disorders: a study among the general population of six European countries." *Acta Psychiatrica Scandinavica* 113.6 (2006): 492-500.

[5] Stein, Murray B., et al. "Social anxiety disorder and the risk of depression: a prospective community study of adolescents and young adults." *Archives of general psychiatry* 58.3 (2001): 251-256.

[6] Rodebaugh, Thomas L., Robert M. Holaway, and Richard G. Heimberg. "The treatment of social anxiety disorder." *Clinical Psychology Review* 24.7 (2004): 883-908.

[7] Chakraborty, Abhinandita. "Exploring the root causes of examination anxiety: effective solutions and recommendations." *International Journal of Science and Research (IJSR)* 12.2 (2023): 1096-1102.

[8] Feldman, Omrit, et al. "Inquiry based stress reduction (IBSR) improves overall stuttering experience among adults who stutter: a randomized controlled trial." *Journal of clinical medicine* 10.10 (2021): 2187.

[9] Saputri, Nova Vivi Clara, Adi Rahmat, and Yanti Hamdiyati. "Using the ibsr technique as a psychological intervention to alleviate student stress in biology learning: Impacts on motivation, knowledge construction, and cognitive anxiety." *Biosfer: Jurnal Pendidikan Biologi* 17.2 (2024): 508-522.

[10] Zadok-Gurman, Tzofnat, et al. "Effect of inquiry-based stress reduction (IBSR) intervention on well-being, resilience and burnout of teachers during the COVID-19 pandemic." *International journal of environmental research and public health* 18.7 (2021): 3689.

[11] Luff, Jacqueline, and Marieke Ledingham. "Exploring Inquiry-based stress reduction (ibsr) as a counselling intervention." (2017).

[12] Krispenz, Ann, and Oliver Dickhäuser. "Effects of an inquiry-based short intervention on state test anxiety in comparison to alternative co** strategies." *Frontiers in psychology* 9 (2018): 201.

[13] Wang, Yimeng, et al. "Understanding Attitudes and Trust of Generative AI Chatbots for Social Anxiety Support." *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems*. 2025.

[14] Nomura, Tatsuya, et al. "Do people with social anxiety feel anxious about interacting with a robot?." *Ai & Society* 35.2 (2020): 381-390.

[15] Horigome, Toshiro, et al. "Virtual reality exposure therapy for social anxiety disorder: a systematic review and meta-analysis." *Psychological medicine* 50.15 (2020): 2487-2497.

[16] Hildebrand, Anne Sophie, et al. "Self-guided virtual reality therapy for social anxiety disorder: a study protocol for a randomized controlled trial." *Trials* 23.1 (2022): 395.

[17] Caponnetto, Pasquale, et al. "The simulation game—virtual reality therapy for the treatment of social anxiety disorder: a systematic review." *International journal of environmental research and public health* 18.24 (2021): 13209.

[18] Anderson, Page, Barbara O. Rothbaum, and Larry F. Hodges. "Virtual reality exposure in the

treatment of social anxiety." *Cognitive and Behavioral Practice* 10.3 (2003): 240-247.

[19] Boadu, Dennis Opoku, et al. "AI and VR-Powered Interventions for Social Anxiety: A Review." *International Journal of Virtual and Augmented Reality (IJVAR)* 7.1 (2025): 1-27.

[20] Åhs, Fredrik, Peter Mozelius, and Felix Dobslaw. "Artificial intelligence supported cognitive behavioral therapy for treatment of speech anxiety in virtual reality environments." *ECIAIR 2020*. Vol. 2. Academic Conferences and Publishing International Limited, 2020.

[21] Smernoff, Eric, Inbal Mitnik, and Shahar Lev-Ari. "The effects of Inquiry-Based Stress Reduction (IBSR) on mental health and well-being among a non-clinical sample." *Complementary therapies in clinical practice* 34 (2019): 30-34.

[22] Krispenz, Ann, and Oliver Dickhäuser. "Reduction of chronic stress and trait anxiety by inquiry of cognitive appraisals with the inquiry-based stress reduction (IBSR) method." *Open Psychology* 1.1 (2019): 185-199.

[23] Kählke, Fanny, et al. "Efficacy of an unguided internet-based self-help intervention for social anxiety disorder in university students: A randomized controlled trial." *International journal of methods in psychiatric research* 28.2 (2019): e1766.

[24] Šipka, Dajana, et al. "Factor structure of the Social Phobia Scale (SPS) and the Social Interaction Anxiety Scale (SIAS) in a clinical sample recruited from the community." *BMC psychiatry* 23.1 (2023): 646.

[25] Lindner, Philip, et al. "Clinical validation of a non-heteronormative version of the Social Interaction Anxiety Scale (SIAS)." *Health and Quality of Life Outcomes* 11.1 (2013): 209.

[26] Caballo, Vicente E., et al. "The assessment of social anxiety through five self-report measures, LSAS-SR, SPAI, SPIN, SPS, and SIAS: A critical analysis of their factor structure." *Behavioral Psychology/Psicología Conductual* 21.3 (2013).

[27] Hambrick, James P., et al. "The experience of disability and quality of life in social anxiety disorder." *Depression and anxiety* 18.1 (2003): 46-50.

[28] Hedman, Erik, et al. "Internet administration of self-report measures commonly used in research on social anxiety disorder: A psychometric evaluation." *Computers in human behavior* 26.4 (2010): 736-740.

[29] Peters, Lorna. "Discriminant validity of the social phobia and anxiety inventory (SPAI), the social phobia scale (SPS) and the social interaction anxiety scale (SIAS)." *Behaviour research and therapy* 38.9 (2000): 943-950.

[30] Kupper, Nina, and Johan Denollet. "Social anxiety in the general population: introducing abbreviated versions of SIAS and SPS." *Journal of affective disorders* 136.1-2 (2012): 90-98.

[31] Wong, Quincy JJ, et al. "Measurement equivalence of the Social Interaction Anxiety Scale (SIAS) and Social Phobia Scale (SPS) across individuals with social anxiety disorder from Japanese and Australian sociocultural contexts." *Journal of Affective Disorders* 243 (2019): 165-174.

[32] Heinrichs, Nina, et al. "Validität und reliabilität der social interaction anxiety scale (SIAS) und der social phobia scale (SPS)." *Verhaltenstherapie* 12.1 (2002): 26-35.

[33] Krispenz, Ann, and Oliver Dickhäuser. "Effects of an inquiry-based short intervention on state test anxiety in comparison to alternative co** strategies." *Frontiers in psychology* 9 (2018): 201.

[34] Riley, Megan E. *One-Week Brief Mindfulness Training: A Stress Reduction Tool for Educators*. Diss. Regent University, 2022.

[35] Rodebaugh, Thomas L., et al. "Convergent, discriminant, and criterion-related validity of the social phobia and anxiety inventory." *Depression and Anxiety* 11.1 (2000): 10-14.

[36] Yap, Marie BH, et al. "Parents in prevention: a meta-analysis of randomized controlled trials of parenting interventions to prevent internalizing problems in children from birth to age 18." *Clinical psychology review* 50 (2016): 138-158.

[37] Weinstock, Lisa S. "Gender differences in the presentation and management of social anxiety

disorder." *Journal of Clinical Psychiatry* 60.9 (1999): 9-13.

[38] Caballo, Vicente E., et al. "Differences in social anxiety between men and women across 18 countries." *Personality and individual differences* 64 (2014): 35-40.

[39] Asher, Maya, and Idan M. Aderka. "Gender differences in social anxiety disorder." *Journal of clinical psychology* 74.10 (2018): 1730-1741.

[40] Arrais, Kátia C., et al. "Social anxiety disorder women easily recognize fearfull, sad and happy faces: the influence of gender." *Journal of Psychiatric Research* 44.8 (2010): 535-540.

[41] Zimmerman, Jacob, Amanda S. Morrison, and Richard G. Heimberg. "Social anxiety, submissiveness, and shame in men and women: A moderated mediation analysis." *British Journal of Clinical Psychology* 54.1 (2015): 1-15.

[42] Tolman, Richard M., et al. "Impact of social anxiety disorder on employment among women receiving welfare benefits." *Psychiatric Services* 60.1 (2009): 61-66.

[43] Açmaz, Gökhan, et al. "Level of anxiety, depression, self-esteem, social anxiety, and quality of life among the women with polycystic ovary syndrome." *The Scientific World Journal* 2013.1 (2013): 851815.

[44] Ratnasari, Shofiana Eva, Israh Pratiwi, and Hayyu Wildannisa. "Relationship between body image and social anxiety in adolescent women." *European Journal of Psychological Research* 8.1 (2021): 65-72.

[45] Turk, Cynthia L., et al. "An investigation of gender differences in social phobia." *Journal of anxiety disorders* 12.3 (1998): 209-223.

[46] Xu, Yang, et al. "Gender differences in social anxiety disorder: Results from the national epidemiologic sample on alcohol and related conditions." *Journal of anxiety disorders* 26.1 (2012): 12-19.

[47] Çelebi, İsmet, et al. "The moderating role of social anxiety in the effect of self-esteem on attitude of violence against women." *Women's Studies International Forum*. Vol. 106. Pergamon, 2024.

Appendix

Social Interaction Anxiety Scale (SIAS)

Instructions: For each item, please circle the number to indicate the degree to which you feel the statement is characteristic or true for you. The rating scale is as follows:

0 = **Not at all** characteristic or true of me.
1 = **Slightly** characteristic or true of me.
2 = **Moderately** characteristic or true of me.
3 = **Very** characteristic or true of me.
4 = **Extremely** characteristic or true of me.

CHARACTERISTIC	NOT AT ALL	SLIGHTLY	MODERATELY	VERY	EXTREMELY
1. I get nervous if I have to speak with someone in authority (teacher, boss, etc.).	0	1	2	3	4
2. I have difficulty making eye contact with others.	0	1	2	3	4
3. I become tense if I have to talk about myself or my feelings.	0	1	2	3	4
4. I find it difficult to mix comfortably with the people I work with.	0	1	2	3	4
5. I find it easy to make friends my own age.	0	1	2	3	4
6. I tense up if I meet an acquaintance in the street.	0	1	2	3	4
7. When mixing socially, I am uncomfortable.	0	1	2	3	4
8. I feel tense if I am alone with just one other person.	0	1	2	3	4
9. I am at ease meeting people at parties, etc.	0	1	2	3	4
10. I have difficulty talking with other people.	0	1	2	3	4
11. I find it easy to think of things to talk about.	0	1	2	3	4
12. I worry about expressing myself in case I appear awkward.	0	1	2	3	4
13. I find it difficult to disagree with another's point of view.	0	1	2	3	4
14. I have difficulty talking to attractive persons of the opposite sex.	0	1	2	3	4
15. I find myself worrying that I won't know what to say in social situations.	0	1	2	3	4
16. I am nervous mixing with people I don't know well.	0	1	2	3	4
17. I feel I'll say something embarrassing when talking.	0	1	2	3	4
18. When mixing in a group, I find myself worrying I will be ignored.	0	1	2	3	4
19. I am tense mixing in a group.	0	1	2	3	4
20. I am unsure whether to greet someone I know only slightly.	0	1	2	3	4

Experiment Device: Meta Quest Pro

Purpose of Source Code Files

AI Module

- Chat Folder: Handles AI conversation functions
    - ChatManager.cs: Manages the conversation flow and state
    - RealtimeAPIWrapper.cs: Wrapper for real-time API calls
- Core Folder: Core AI configuration
    - AIConfig.cs: Base configuration for AI services
    - AIChatConfig.cs: Chat-specific configuration settings

Main Module (Main Application)

- MainManager.cs: Main controller of the application
- SceneManager.cs: Scene loading and management
- XRRootManager.cs: Manages XR-related features
- MemoryBubbleManager.cs: Manages the “thought bubble” UI
- MainContrastManager.cs: Fixed-language generation (demo)
- StartPoint.cs: The initial point entered upon scene load
- LanguageType.cs: Definition of language types

Test Module

- AITest.cs: Test script for AI functionality

System Configuration Overview

Engine: Unity (for scene building) + Visual Studio (for scripting)

AI Model: ChatGPT

Hardware Device: Meta Quest Pro

VR Framework: Unity OpenXR