Next-generation Virtual Exposure Technology for Public Speaker Social Anxiety Reduction in Gen Z Learners

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***Abstract*—Public speaking anxiety among Gen Z students is currently experiencing a significant increase, making it difficult for them to speak in front of an audience. This has been proven to impact their performance and social relationships. Virtual Reality (VR) technology in the Metaverse is an effective training tool for managing public speaking anxiety through various environmental customizations. However, scientific research is needed to better understand which features of the simulated environment are most important for increasing or decreasing participants' discomfort. This study examined the role of visual audience and presentation room characteristics, including realism and unrealism, on perceived anxiety, presence, and realism in an interactive VR public speaking scenario. 85 participants participated in four public speaking sessions and measured heart rate changes throughout the presentation. The results showed that audience and presentation room realism played a significant role in perceived anxiety during virtual public speaking. Specifically, higher levels of realism, as a stimulus, increased anxiety levels among Gen Z students. Conversely, lower levels of acoustic realism were associated with lower anxiety among presenters during public speaking. Furthermore, a relationship between realism and anxiety was found, and a relationship between the duration of practice and reduced anxiety. Overall, our results demonstrate that virtual environmental features play a key role in creating a realistic public speaking experience. They can be used as a social skills training strategy to help reduce academic difficulties and improve public speaking anxiety among Gen Z students.**

***Keywords*—Gen Z, Metaverse, public speaking anxiety, social anxiety, Virtual Reality (VR)**

I. Introduction

Oral communication constitutes one of the most pivotal forms of public speaking. It is universally esteemed as one of the most sought-after competencies by employers within organizational frameworks [1]. Consequently, higher education institutions are increasingly dedicating efforts to refining students' oral communication skills, aiming to align graduates with the exigencies of the labor market and enhance their employability prospects. However, the task of inculcating these skills in the contemporary era is further complicated by the pervasive phenomenon of public speaking anxiety, also termed Glossophobia [2]. Classified as a social phobia or Social Anxiety Disorder (SAD), Glossophobia stands as one of the most ubiquitous fears globally, afflicting nearly 75% of the population [3]. The manifestations of this anxiety extend beyond psychological distress, producing physiological symptoms such as xerostomia, elevated blood pressure, and perspiration, alongside an acute fear of humiliation and apprehension regarding negative evaluation by others [4, 5]. These compounded effects—both mental and physical—exert a deleterious influence on university students' academic experiences. In particular, the group of students born 1997–2012, who are considered Generation Z and are growing up with smartphones and social media, are digitally fluent. Extensive smartphone usage, this constant digital immersion, exposure to idealized images of personal success and lifestyles online, is linked to detrimental mental health outcomes. Specifically, these factors may precipitate feelings of inadequacy, isolation, concern, and fear of being judged by others, and social anxiety among Gen Z, who have been shown to report higher levels of social anxiety than preceding generations [6–9].

The trepidation students experience about public speaking is a testament to its pervasive adverse effects on their overall higher education experience. It is incumbent upon higher education institutions to recognize this prevalent anxiety and implement targeted interventions to alleviate the distress associated with practicing oral presentations. While not all learners encounter challenges with public speaking, such tasks have become increasingly prevalent in contemporary times, largely due to the transformative influence of social media on communication, which has diminished opportunities for face-to-face interaction. Among Asian students in particular, there is a pronounced tendency toward reticence in public presentations and even in classroom settings, where fears of judgment may manifest visibly through behaviors such as avoiding eye contact, physical restlessness, perspiration, and speech disfluencies. Although public speaking fear has an overall negative impact on students' higher education experiences, the job market demands graduates with public speaking skills. This skill is indispensable to university education, and students are unlikely to avoid developing public speaking skills. Therefore, schools and educators should develop instructional technologies and tools to reduce the distress students experience when practicing public speaking.

In recent years, the use of virtual reality as a therapeutic modality for anxiety has gained considerable traction, reflecting its rapid evolution as an invaluable aid in healthcare [10]. By virtue of its capacity to immerse individuals in simulations that closely replicate real-world phobic scenarios while circumventing the constraints inherent to physical environments, virtual reality emerges as a potent and innovative approach to addressing social phobias, including the pervasive fear of public speaking [11]. This methodology holds significant promise as an efficacious intervention for mitigating the symptoms of social anxiety disorders. Similar commercial solutions are presently available; however, these offerings are predominantly aimed

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at enterprise use cases. While such use cases are undeniably beneficial, they make these solutions less accessible to the average individual who needs such support. Moreover, the customization of virtual environments to accommodate users' unique needs remains a challenge [12].

Furthermore, the study seeks to address pivotal research questions about the Metaverse as a valuable virtual domain that can be harnessed as an academic instrument to mitigate public speaking anxiety among Gen Z students. By providing immersive, simulated environments, Metaverse enables students to practice and refine their oratory skills, thereby enhancing their comprehension of academic content and bolstering their prospects for employment and career progression. This research hypothesizes that VR development can help reduce public presentation nerves among Gen Z students, who fear public speaking.

This paper presents a literature review in Section II. Section III outlines the design framework, including implementation strategies and key decisions. Section IV reports and discusses empirical findings. Section V addresses the limitations of this research and future work. Finally, Section VI presents the study's conclusions.

II. Literature Review

A. Public Speaking Anxiety

Public Speaking Anxiety (PSA), often referred to as glossophobia, comes from the Greek glōssa, meaning tongue, and phobos, meaning fear. PSA falls under the category of Social Anxiety Disorder (SAD), which can directly affect a person's public speaking and interpersonal engagement. SAD is delineated as a persistent fear or anxiety arising from social interactions or occupational contexts where the individual encounters unfamiliar people or faces the prospect of evaluative scrutiny. This condition is formally recognized as a mental health diagnosis within the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) [12]. PSA, the apprehension or fear associated with speaking in public or engaging in verbal communication more broadly [2], represents one of the most prevalent fears encountered across diverse age groups and professional domains. This form of anxiety can profoundly hinder an individual's capacity to articulate ideas effectively before an audience, whether in structured contexts such as professional conferences or informal scenarios like family gatherings. Understanding its etiology, manifestations, and mitigation strategies is indispensable for fostering personal and professional development.

The study of public speaking anxiety among students holds considerable importance [13–17]. For college students, public speaking is often an academic necessity, requiring proficiency in oral presentations before an audience, such as in classroom settings. This requirement can pose significant challenges for individuals lacking confidence in their speaking abilities [18]. Furthermore, physiological manifestations of anxiety can adversely impact performance. These symptoms may include trembling or shaking, cold and clammy hands, a quivering voice, an accelerated heartbeat, excessive sweating, blushing, dizziness, shortness of breath, gastrointestinal discomfort, or memory lapses regarding known or prepared material. Notably, it is essential to recognize that the level of anxiety experienced is closely associated with its outward expression. Moreover, some university students respond by avoiding public speaking, and the experience of failure after a classroom presentation can lead to distress or embarrassment. Extensive research has been conducted to investigate public speaking anxiety, with findings consistently revealing that students often encounter significant challenges when speaking in public. A common thread among these studies is that students frequently experience heightened nervousness and a strong desire to avoid making mistakes, fearing that imperfections might render them foolish or incompetent [13, 19–24].

Public speaking is widely recognized as one of the most anxiety-inducing experiences for individuals, as evidenced by studies conducted within both community and academic settings. A survey of students at two universities in the United Kingdom revealed that the majority (80%) identified delivering oral presentations as a primary trigger for social anxiety, significantly impacting their academic performance and well-being [25]. Similarly, public speaking is a pervasive fear among U.S. college students, with 61% ranking it as their second greatest concern, surpassed only by fears of death and financial instability [26]. Further corroborating this, a recent study reported that 64% of U.S. undergraduates experience fear of public speaking [16]. Phenomenological analyses of students' experiences with oral presentations frequently employ quantitative methodologies to evaluate their proficiency in articulating ideas and demonstrating comprehension of academic material [27]. Nevertheless, despite the pedagogical emphasis on oral presentations, they persist as a considerable source of stress and anxiety for learners [28]. These enduring challenges, which significantly affect students' educational experiences, remain insufficiently addressed within academic environments [29, 30]. This study sought to explore the potential of virtual reality technology as a training tool to alleviate the stress and anxiety students associate with oral presentations.

B. Metaverse Technology for Public Speaking Anxiety

The potential of digital technology in the part of virtual technology to be integrated into various areas of medicine and psychology has been demonstrated with mixed success, with VR being used for medical training [31], treatment of eating disorders and body image [32], post-traumatic stress and obsessive-compulsive disorder [33], assessment of pain [34, 35], and phobias [36]. The ability of VR to measure behavior within ecologically valid environments while maintaining a high level of safety and control makes VR another potential treatment option [37–40]. Further noted that VR allows therapists to select and tailor content to the individual needs of their patients, and that VR exposure therapy is at least as effective and yields results similar to those of current treatments [38].

Virtual Reality (VR) exposure therapy has demonstrated significant efficacy in addressing phobias, effectively reducing fear associated with real-world stimuli [41–43]. A recent systematic review highlighted the effectiveness of VR exposure therapy for various phobias, including social phobia [44]. This therapeutic approach enables patients to confront feared situations or environments gradually while fully immersed in a controlled VR setting [45]. By providing a safe and controlled environment, VR facilitates the incremental expansion of anxiety tolerance, a cornerstone of effective exposure therapy [46]. Moreover, as noted by [39], the use of virtual environments circumvents many of the practical constraints associated with real-world exposure, offering a highly adaptable and valuable method for treating Social Anxiety Disorder (SAD).

In the context of public speaking anxiety therapy, Virtual Reality (VR) has proven to be an effective intervention for addressing public speaking anxiety among students, offering a less intrusive alternative to traditional therapeutic methods involving physical interaction [47]. Empirical studies have consistently supported the efficacy of VR exposure therapy in alleviating public speaking anxiety. Furthermore, VR-based interventions have demonstrated the additional benefit of reducing student dropout rates, further underscoring their potential utility in educational contexts [48].

The rapid evolution of digital virtual reality technologies has given rise to the Metaverse, a concept derived from the fusion of 'meta,' signifying transcendence and virtuality, and 'universe,' denoting a Three-Dimensional (3D) virtual domain populated by real-life avatars [2]. This innovative amalgamation of Virtual Reality (VR) universes enables individuals to interact, socialize, collaborate, engage in recreational activities, and innovate within immersive digital environments [49, 50]. Within the Metaverse, users can connect with diverse avatars, participate in professional and leisure activities, and partake in economic exchanges facilitated by distinctive digital assets known as Non-Fungible Tokens (NFTs). Particularly appealing to adolescents, the Metaverse resonates with their receptiveness to novel cultural paradigms and their capacity to foster independent cultural identities through virtual spaces [2].

The success of Metaverse technology in treating social anxiety disorder and improving social interaction and communication skills. For example, Virtual Reality Exposure Therapy (VRET) uses virtual reality simulations to expose patients to fearful situations in a caring and safe environment [51]. This approach has been proven effective in treating a variety of mental health conditions, including phobias, PTSD, anxiety, and depression. It has been found to significantly reduce symptoms of phobias and PTSD [52], thus improving patients' quality of life. Additionally, virtual reality can improve social skills training. Virtual reality can reduce social anxiety and improve social skills in people with social anxiety disorder [53]. Immersion in a virtual environment has been shown to enhance empathy and prosocial behaviors, particularly among individuals with autism spectrum disorder [54]. The Metaverse introduces novel avenues for social engagement and decreased social isolation [53]. Moreover, prolonged engagement in virtual worlds can reshape social interactions, often with positive effects on mental health. A conceptual framework analyzing social dynamics within the Metaverse identified key elements—social presence, supportive interactions, and social self-efficacy—as being associated with reduced feelings of loneliness. This highlights Metaverse as a validating and inclusive platform, particularly beneficial for individuals facing barriers to in-person communication [55].

III. Materials and Methods

A. Research Model

This research presents the research framework shown in Fig. 1, consisting of 3 parts. The first part is Input: Participants & Resources, which consists of users (Students), training content, which is presentation content that is about User Experience (UX) and User Interface (UI) design theories in the context of a website, totaling 300 words, with four different contents (Presentation Content), and Tools. Users will use a web browser as a tool to access VR Public Speaking. The next part is Process: VR Development, which develops four types of simulation scenarios or Presentation VR Rooms: 1) High realism: human-like avatar and realistic presentation room, 2) Partial realism: human-like avatar and unrealistic presentation room, 3) Moderate realism: cartoon avatar and realistic presentation room, and 4) Low realism: cartoon avatar and unrealistic presentation room. This work used Unity and Maya software to develop and publish on the website Spatial.io for users. The last part is the Measures section, which will measure the results from the student group. This section presents the Result: Measures, which show the levels of nervousness detected through heart rate monitoring on a smartwatch.

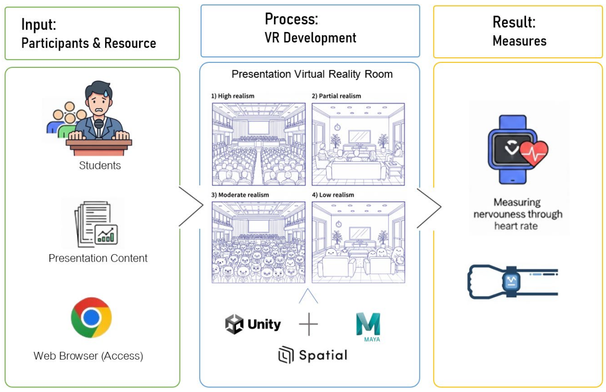


Fig. 1. The research framework.

B. Participants and Resources

Participants were selected through self-registration via a Google Form, with a 60-day registration period. Eligibility criteria required applicants to be undergraduate students majoring in Information Technology in the Faculty of Science and Technology, Suan Sunandha Rajabhat University, Thailand, currently in their first to fourth year of study. The sample size was determined using G*Power software, based on a significance level of $\alpha = 0.05$ and a statistical power (1-β) of 0.80. A total of 85 participants ($N = 85$) were aged 20–25 years, comprising 34 females (40%) and 51 males (60%). Nine participants reported prior experience with Virtual Reality, while the remaining 68 (80%) did not. Notably, over 95% of participants feared public speaking after taking the public speaking fear test. This work proposal was conducted in accordance with the ethical principles of the Declaration of Suan Sunandha Rajabhat University Ethics Committee. Users will use a web browser, such as Chrome, to access the virtual presentation room on the spatial.io platform.

C. Experimental Design

The experimental design examined how varying levels of graphic realism affect anxiety and physiological responses during a public-speaking performance in virtual reality. The subjects were required to participate in four public speaking performance trials. There are four simulation scenarios (room types) as follows:

(1) High realism: The scenario consists of realistic human audience avatars and the realistic presentation room (RH_RR).
(2) Partial realism: The scenario consists of realistic human audience avatars and the unrealistic presentation room (RH_FR).
(3) Moderate realism: The scenario consists of non-human audience avatars and the realistic presentation room (FH_RR).
(4) Low realism: The scenario consists of non-human audience avatars and the unrealistic presentation room (FH_FR).

This research on public speaking used the presenter's natural voice to deliver the presentation and respond to inquiries. In contrast, the audience's genuine voices were used to pose questions. The presentation covered User Experience (UX) and User Interface (UI) design theories in the context of Conference National's website development. The presentation content and time will be prepared in advance and evaluated using the Index of Consistency (IOC) [56] by five specialists in information technology or educational technology, with the content consistency score exceeding 0.8 (the IOC evaluation threshold is 0.5, and the maximum is 1.0). Each participant will spend approximately 20 min over four weeks.

D. Visual Reality Presentation Scenarios and Procedures

Fig. 2. The simulation scenario for partial realism.

Fig. 3. The simulation scenario for high realism.

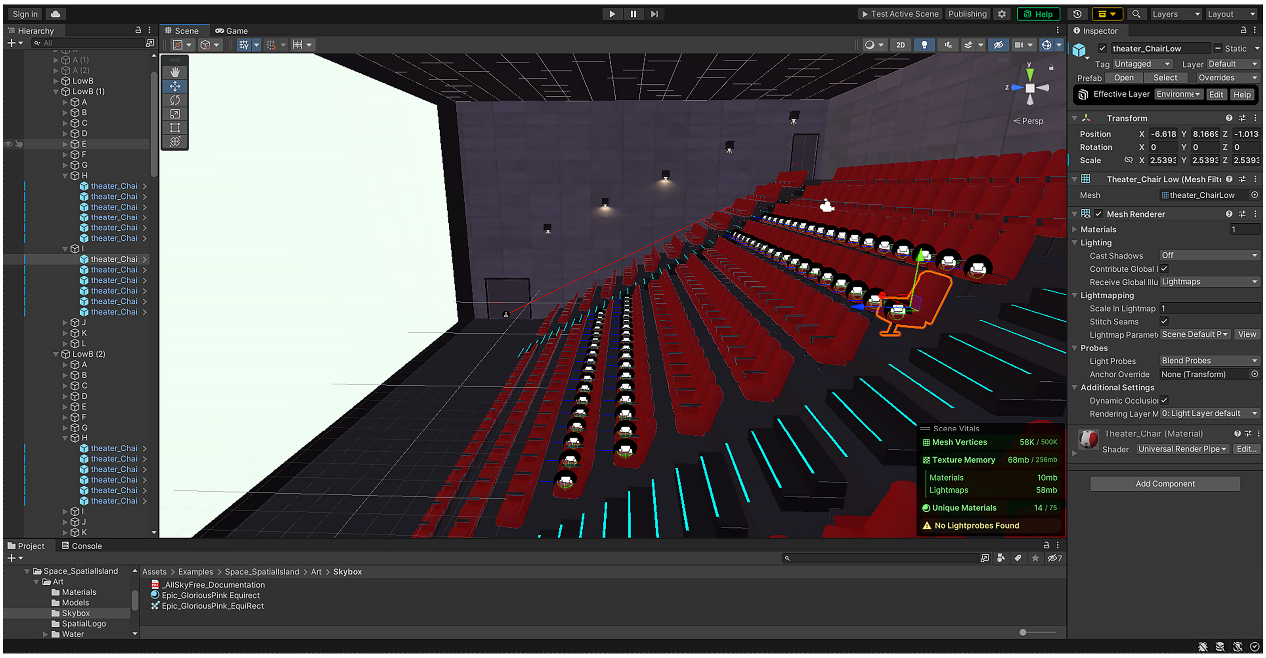


Fig. 4. The simulation scenario for high realism creation using unity.

User devices are smartphones, tablets, or personal computers with microphones and speakers. The minimum internet speed requirement is 10 Mbps download and 2 Mbps upload, resulting in a highly realistic presentation of the avatar, the room, the presenter's voice, and the Q&A between the presenter and the audience. The environment, presentation room, and avatars were meticulously crafted utilizing the tools available on Spatial.io to generate both human-like and non-human-like avatars. The presentation room that looks like a real presentation room, intentionally designed to deviate from the conventional appearance of a presentation room in Spatial.io show in Fig. 2 and Fig. 3, was developed using Unity and Maya software and subsequently imported into the libraries of Spatial.io for deployment as Fig. 4. Through their avatars, both the presenter and audience can navigate the virtual space with lifelike fluidity, enabling them to sit, listen, walk, and activate their microphones to speak, type messages, and express reactions via emojis. The testing process is initiated by disseminating an email containing a Spatial.io link to the designated sample group. Participants, including the presenter and audience members, are required to join the virtual space five minutes prior to the scheduled presentation. The presenter is allotted 10 to 20 minutes to prepare and deliver the presentation. Upon completion, the audience may activate their microphones to ask questions, which the presenter will respond to. The Q&A segment allows one participant to speak at a time, and all presentation sessions are recorded.

E. Measurements

Based on the normative data and statistical distributions reported in the systematic reviews by Achary *et al.* [57, 58], the Root Mean Square of Successive Differences (RMSSD), a heart rate variability measure, can be used as a criterion for classifying heartbeat patterns during public speaking sessions. To establish the most accurate RMSSD criteria for young adults (aged 20–25), this work integrates the findings from both studies. Specifically, [57] reports that the young group (<40 years) has the highest autonomic activity, with baseline values that are naturally higher than the general population average of 42 ms reported by Nunan *et al.* [58]. Therefore, this study defined the Heartbeat Pattern Index (HPI) into four indices based on quantifying the RMSSD measurements as follows:

- HPI 1: Strong Fluctuation (SF) indicates low variance, with an index value of 1 when the RMSSD threshold is less than 25 ms. Heartbeat spikes rapidly (tachycardia) when the speaker stumbles over a word. It may drop slightly when the speaker takes a breath, then surge again. The fluctuation is the visible pulse jumping as the body struggles to find a steady rhythm under pressure. It reflects high physiological stress, or due to initial shock or high anxiety.
- HPI 2: Shifting Shyness (SS) is characterized by medium variance, alternating episodes of accelerated and decelerated heart rate variability, with an index value of 2 when the RMSSD threshold is between 25 and 47 ms. This indicates the heartbeat is beginning to break free from the rigidity. The speaker's autonomic nervous system is starting to adapt and move away from high to moderate anxiety, but is not yet fully habituated.
- HPI 3: Stable Control (SC) indicates high variance, reflecting minimal fluctuation between faster and slower heart rate variability, with an index value of 3 when the RMSSD threshold is between 48 and 85 ms. It indicates that the heart is no longer locked in a state of stress or anxiety. This heartbeat pattern reflects a speaker who has gained greater control over their pace and confidence, moving away from moderate to low anxiety toward physiological resilience.
- HPI 4: Stable Tone (ST) indicates very high variance, denoting a stable, largely unchanging heart rate during speaking, with an index value of 4 when the RMSSD threshold is exceeded at 85 ms or more. The high RMSSD value indicates that the heart maintains a healthy, flexible rhythm responsive to the speaker's breathing rather than being locked into a stress response. The speaker is in a state of good physiological control, indicating appropriate

autonomic regulation during public speaking with low anxiety.

Physiological data were collected from 85 participants within four presentation-simulation rooms (RH_RR, RH_FR, FH_RR, and FH_FR) developed using Metaverse technology. Each room continuously monitored heart rate dynamics over four consecutive weeks, with each session spaced one week apart. The content presented each week is as follows:

- P1 Introduction and presentation topic (3 min).
- P2 Presentation of familiar content about website user experience and interface design (7 min).
- P3 Conclusion (4 min).
- P4 Closing remarks and Q&A from the audience (6 min).

The chi-square test of independence was employed to assess whether a statistically significant association exists between chamber type and heartbeat pattern. The hypotheses guiding this analysis were specified as follows:

H_0: There is no significant relationship between chamber type and heartbeat pattern.

H_1: A significant relationship exists between chamber type and heartbeat pattern.

An identical inferential framework was applied to examine the association between time intervals and heartbeat patterns. The corresponding hypotheses were articulated as:

H_0: There is no significant relationship between time interval and heartbeat pattern.

H_1: A significant relationship exists between time interval and heartbeat pattern.

Additionally, to account for the non-independence of repeated observations within participants, a Linear Mixed-Effects Model (LMM) was utilized. A mixed-effects model accounts for the fact that some Gen Z students are naturally more anxious than others (the random effect) while isolating the actual impact of virtual room realism (the fixed effect). In addition to heart rate-related measurements, all participants were required to complete a self-report assessment using the 34-statements Personal Report of Public Speaking Anxiety (PRPSA) [59]. The instrument should be administered as a self-report Likert-scale assessment, in which students rate each of the 34 statements from 1 (strongly disagree) to 5 (strongly agree). Once the values are summed using McCroskey's formula, the resulting score (ranging from 34 to 170) can be categorized into discrete levels of the student's anxiety: low (<98), moderate (98–131), or high (>131). The first assessment of each individual's true anxiety level using this instrument was conducted during the pre-training period (seven days before the start of the first week of training). Afterward, all participants were required to complete a self-report assessment after each week of public speaking for four weeks. The assessment results were then compared to determine their anxiety levels.

IV. Result and Discussion

Data from 85 participants who took part in the work employing a developed virtual public speaking presentation room technology were collected. During the experiment, participants wore smartwatches that continuously monitored their heart rate variability. The use of smartwatches was intentionally selected to minimize participant anxiety, as their familiar watch-like form factor aligns with the devices commonly worn by Generation Z. Heart rate variability measurements captured by the smartwatches were stored in a central database and subsequently analyzed to evaluate physiological fluctuations across four presentation periods, within four distinct virtual rooms, and across heartbeat pattern index. The comparison of heartbeat pattern index results by room types or virtual environments is shown in Fig. 5.

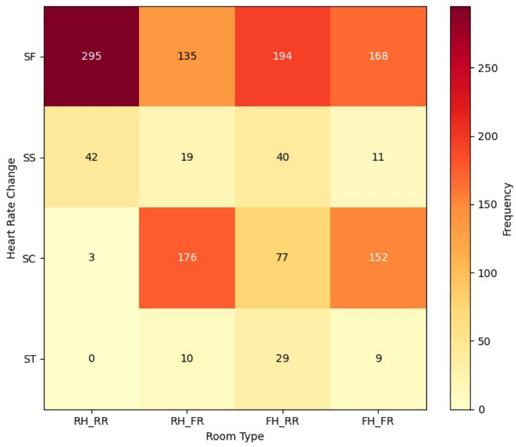


Fig. 5. The heat map of heartbeat patterns by room type.

In Fig. 5, the heat map reveals clear and meaningful patterns in how the realism levels of different environments and audience types influenced speakers' heart rate variability during public speaking. Overall, highly realistic scenarios, particularly those simulating both a human avatar audience and a realistic presentation room (RH_RR), elicited the highest physiological arousal, as evidenced by a large number of SF (low variability) response intensities ($n = 295$), indicating sustained heart rate increases throughout the presentation. This result suggests that highly realistic virtual environments elicit stress responses that closely resemble real-world public speaking situations. Such realism appears to increase cognitive and emotional load, possibly due to the higher social evaluation pressure. In contrast, partial realistic environments with human avatars (RH_FR) showed a more dispersed pattern in SF, SS, and SC, indicating moderate stress but less sustained physiological arousal compared to fully realistic settings. Reduced environmental realism may lower immersion and decrease perceived social threat, resulting in more varied heartbeat patterns.

The condition with non-human avatars, particularly the low realism environment (FH_FR), exhibited significantly lower SF response frequencies and higher expression in the SC and ST categories. This suggests that when both the anthropomorphism of the audience and the realism of the room were reduced, presenters experienced less physiological stress and exhibited more stable heartbeat patterns. The FH_RR condition, which combined a non-human avatar with a realistic room, produced intermediate effects, reinforcing the idea that both audience type and the realism of the environment jointly modulate arousal.

The heat map in Fig. 6 shows the number of participants who experienced a change in heartbeat pattern across four sessions (four weeks) of public speaking, providing clear insights into how presenters physiologically adapted or continued to struggle throughout each week of public speaking as virtual reality technology evolved. A significant turning point appeared in P3, where the SF response rapidly decreased to 89. This change coincided with the summary segment presented during the speaker's third listening session. This decrease indicates that repeated listening sessions began to induce some habituation, decreased sympathetic nervous system activity, and allowed the speaker to regain physiological stability. Consequently, the SC (low variance) group showed a significant increase in P3 (n = 207), indicating that many speakers exhibited calmer, more controlled heartbeat patterns during this phase.

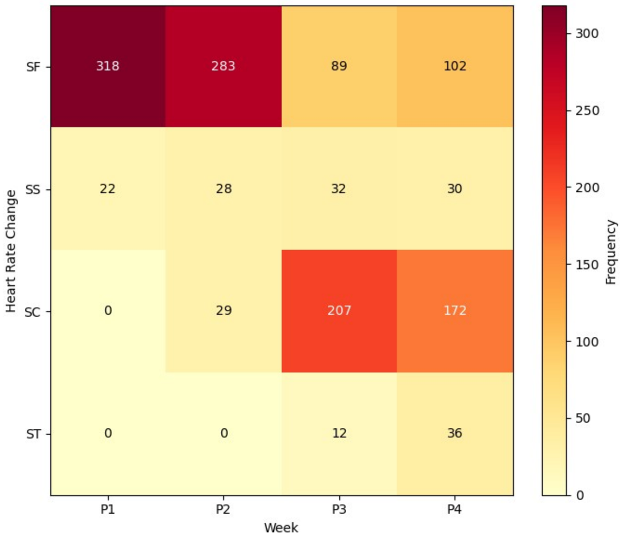


Fig. 6. The heat map of heartbeat patterns by week.

In week 4 (P4), the heartbeat pattern changed again, with SF responses increasing slightly to 102, and SC responses remaining high (n = 172). The Q&A session introduced unpredictable audience interaction, likely eliciting a slight stress response again, while maintaining the benefit of the previous listening session. The increase in ST (very low variance) to $n = 36$ in P4 was notable, suggesting that a subset of presenters was highly physiologically stable by the end of the session, potentially reflecting increased confidence or relief at task completion.

The box plots in Fig. 7 comparing heart rate variability across four levels of room and audience realism provide a clear picture of how different virtual presentation environments influence physiological arousal during public speaking. The distribution patterns reveal significant differences in stress responses, particularly across audience type and environmental fidelity.

The RH_RR (high realism) condition had the lowest median but the widest spread, including the most severe outliers, which approached 300 events. This combination suggests that, although many presenters experienced moderate heart rate fluctuations, a subgroup exhibited particularly high physiological reactivity in this entirely realistic environment. The presence of a highly realistic room and a representative human audience likely increased social evaluative pressure, leading to sporadic but intense sympathetic nervous system activation. Thus, RH_RR appears to amplify stress, particularly in individuals with high realism sensitivity. In the RH_FR (partial realism) condition, the median heartbeat pattern was higher, and the interquartile range expanded significantly. This suggests that reducing room realism while maintaining an anthropomorphic audience led to persistently higher levels of presenter stress. The presence of an anthropomorphic audience remained a primary stressor. At the same time, partial room realism may have eliminated visual cues that helped presenters regulate or anchor themselves, leading to broader and more consistent physiological arousal.

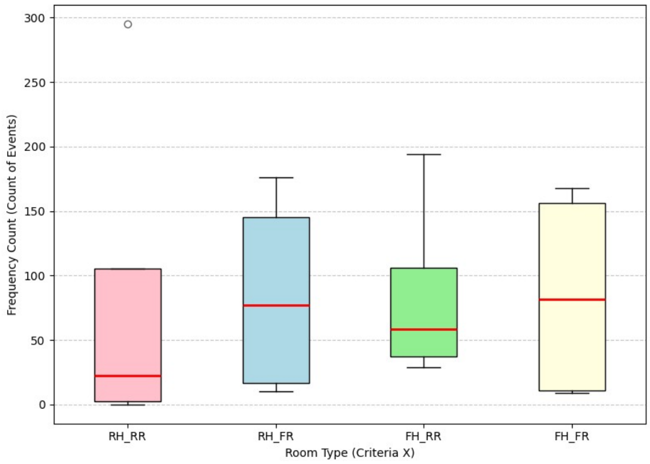


Fig. 7. Boxplot of heartbeat patterns by room.

In contrast, the FH_RR (moderate realism) condition, which involved a non-human avatar in a realistic room, had a narrower median and a tighter distribution. This indicates a decrease in perceived social threat, as the presence of non-human spectators decreased the feeling of being evaluated. Although variance persisted, the distribution showed a more predictable and manageable heartbeat pattern than in the human-avatar condition. Additionally, the FH_FR (low realism) condition has a high median and a wide dispersion similar to RH_FR, but no severe outliers. Although the absence of human avatars directly reduces social pressure, the combination of low-fidelity avatars and unrealistically rendered rooms may produce unfamiliar or ambiguous cues that disrupt emotional regulation, leading to increased physiological responses in some presenters, though not as severe as those seen in RH_RR.

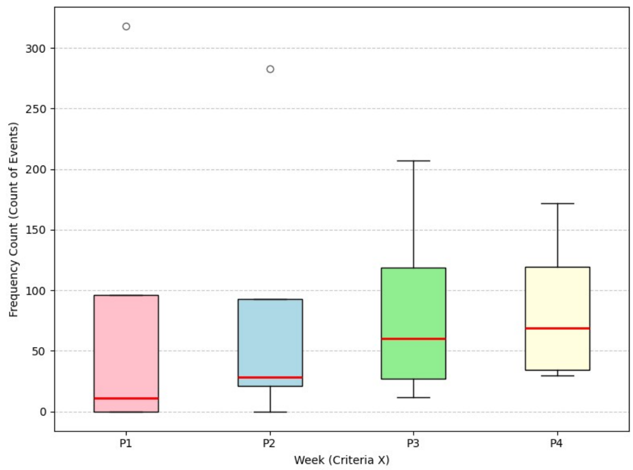


Fig. 8. Boxplot of heartbeat pattern index by week.

Fig. 8 presents a boxplot of Heart Rate (HR) variation for the presenters during each week of speaking (P1–P4), under the X and Y criteria, reflecting their increasing public speaking experience and familiarity with the content and context of their presentations. Overall, P1 and P2 showed a relatively broad distribution of HR values, with significant outliers, indicating a low variance (SF) state consistent with the excitement of first- and second-time speakers. This was particularly evident during the topic introduction (P1), where the pressure of initiation, the need to set the tone, and unfamiliarity led to the highest heart rate variability. In P2, despite the presenters' increasing familiarity with the situation, the content length (7 min) and the complex explanatory task still prompted HR to fall within the SS-SF range, reflecting low to moderate variability.

In P3, the summary of key points showed that the median HR decreased, while the distribution narrowed compared to P1–P2. Although some outliers remained, the overall trend indicated an SS-to-SC state, with a gradual decrease in stress levels as the speaker gained greater control of his pace and confidence. A concise and clearly structured presentation during the conclusion may also reduce HR variability. In P4, the closing and question-and-answer session, the data boxes showed a moderately widespread distribution. However, the median trend was slightly higher than in P3. This increase is consistent with the potential uncertainty introduced by the audience's questions, a factor beyond the presenter's control. This resulted in HR being in the SC-to-SS category, indicating high to moderate variability. Although the speaker became more confident in the final week, the unpredictability of the Q&A still put some pressure on them.

From Table 1, the chi-square test of independence results in examining the association between room type intervals (RH_RR, RH_FR, FH_RR, and FH_FR) and heartbeat pattern indexes (SF, SS, SC, and ST), resulting in rejecting the hypothesis H_0 and accepting H_1: A significant relationship exists between room type and heartbeat pattern at the 0.05 significance level. Results of the chi-square test in Table 2. An identical inferential framework was applied to examine the association between time intervals (P1–P4) and heartbeat pattern index. The chi-square test of independence rejects the null hypothesis H_0 and accepts the alternative hypothesis H_1: a significant relationship exists between week and heartbeat pattern at the 0.05 significance level.

Table 1. The chi-square test for statistically significant association exists between the room type and the heartbeat pattern index

Degrees of freedom (df)	N	Chi-square statistic (χ^2)	Critical value (α = 0.05)	p-value
9	1360	315.12	16.96	<0.001

Table 2. The chi-square test for statistically significant association exists between the week and the heartbeat pattern index

Degrees of freedom (df)	N	Chi-square statistic (χ^2)	Critical value (α = 0.05)	p-value
9	1360	600.14	16.96	<0.001

Based on the Mixed-Effects Model, the LMM is used to analyze the heartbeat pattern index among Gen Z participants. In a mixed-effects framework, the Wald test is used to derive these values, including F-statistics and p-values, as shown in Table 3 and Fig. 9.

Table 3. The result of the LMM analysis of the heartbeat pattern comparing between the week and the simulation scenario (avatar and presentation room)

Factor	df	N	Wald (χ^2)	F-statistic	p-value
Room type	3	1360	45.20	15.06	<0.001
Week	3	1360	1001.11	333.70	<0.001
Room type×Week	9	1360	483.46	53.72	<0.001

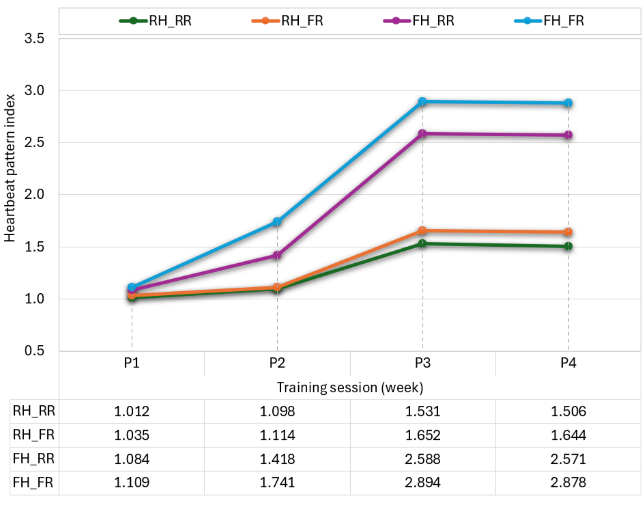


Fig. 9. The mean heartbeat pattern index by training session and simulation scenario.

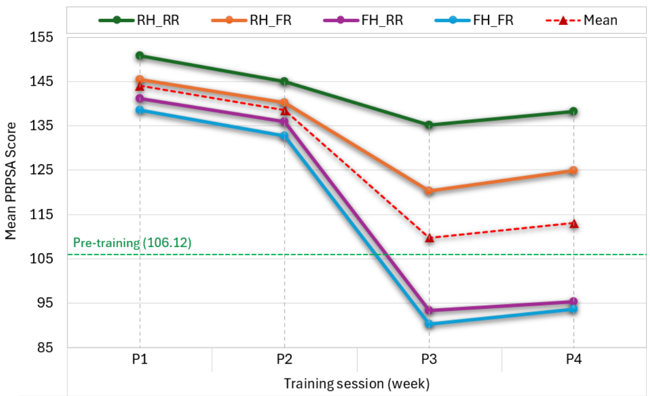
The results of the LMM analysis revealed a highly significant main effect for room type ($F = 15.06$, $p < 0.001$), a highly significant main effect for training week ($F = 333.70$, $p < 0.001$), and a significant room type × week interaction ($F = 53.72$, $p < 0.001$). The significant main effect for room type indicates that the specific configuration of the virtual environment independently dictates the speaker's physiological state throughout training. While all participants initially exhibited the low variance SF pattern during the baseline training session (P1), those in the unrealistic environments demonstrated an accelerated transition through the SS pattern toward the stable, high variance profiles of SC and ST by the fourth session. In contrast, the high realism group (RH_RR) remained significantly closer to the SF pattern. It could be argued that greater realism has a greater impact on physiological stress than an unrealistic environment.

According to Fig. 9, the result reveals a significant upward trend in the heartbeat pattern index as training progresses, indicating physiological adaptation and improved autonomic regulation across all room conditions. While all groups began at a similar baseline in week P1 (approximately 1.0), it gradually increased at P2 and rose significantly between P2 and P3. After that, the heartbeat pattern index showed a slight change at P4. A deep analysis shows a stark divergence by environment: the unrealistic conditions (FH_RR and FH_FR) consistently outperformed the realistic human-audience avatar settings (RH_RR and RH_FR), with the FH_FR group achieving the highest mean heartbeat pattern index (2.894) in week P3. This suggests that while the training is universally effective at increasing physiological resilience, unrealistic virtual environments likely offer a lower social threat threshold. It helps participants manage stress and reduce anxiety better compared to more high realism environments.

Furthermore, the analysis of the PRPSA scores across the four-week training program reveals a clear, non-linear downward trend in public speaking anxiety, characterized by an initial period of high stress followed by a significant habituation phase, as shown in Table 4 and Fig. 10. During the initial session (P1), participants across all conditions experienced initial shock, with a collective mean PRPSA score of 143.99, well above the pre-training trait anxiety baseline of 106.12. As the sessions progressed into P2, a slight adaptation began, with the mean PRPSA marginally decreasing to 138.49. However, the most critical shift occurred at P3, where the mean score plummeted to 109.81, presenting a transition from high anxiety to moderate anxiety through habituation. By P4, scores stabilized at a mean of 113.04, indicating that while the shock of the task had subsided, alertness levels still exhibited some variance.

Table 4. The result of the mean PRPSA scores by training session (week)

Training session	Mean	SD	Max.	Min.	Interpreted
Pre-training	106.12	4.05	123	98	Trait anxiety (baseline)
P1	143.99	5.33	157	132	High anxiety (initial shock)
P2	138.49	10.16	155	105	High anxiety (start to adapt)
P3	109.81	15.54	146	80	Moderate anxiety (habituation)
P4	113.04	17.17	149	76	Moderate anxiety (stable)



	P1	P2	P3	P4
RH_RR	150.78	144.99	135.15	138.28
RH_FR	145.48	140.21	120.39	124.84
FH_RR	141.12	135.99	93.37	95.41
FH_FR	138.58	132.75	90.31	93.62
Mean	143.99	138.49	109.81	113.04

Fig. 10. The mean PRPSA score by training session and simulation scenario.

As shown in Fig. 10, the mean PRPSA scores are displayed for each room condition in each week. For RH_RR (high realism), this condition, featuring a realistic audience in a realistic room, was the most taxing, maintaining the highest anxiety levels, peaking at 150.78 in P1 and ending at 138.28 in P4. Conversely, FH_FR (low realism), the least realistic environment, consistently yielded the lowest scores, dropping as low as 90.31 by week P3. Interestingly, while a Realistic Room (RR) added a slight anxiety premium when paired with real humans, the FH groups (non-human avatars) saw their scores drop significantly below the pre-training baseline of 106.12 by the third week. This suggests that low realism environments may serve as a safe space that allows participants to de-escalate their anxiety faster than high realism settings. As the PRPSA scores dropped sharply at P3, there was a corresponding surge in the heartbeat pattern index. This indicates that the participants were not just feeling less anxious; their autonomic nervous systems were shifting from a state of fight-or-flight (low heartbeat pattern index) to a state of physiological resilience (high heartbeat pattern index).

In addition, this study followed up on the sample group's performance in public presentations by interviewing instructors in two undergraduate courses in the 2025 academic year. The follow-up results showed that the sample group performed well in real public presentations, had reduced presentation anxiety, and, on presentation days, no students were absent. Unlike in previous semesters, when students scheduled to present were frequently absent. Fig. 11 shows the presentations of the Gen Z student sample who presented in public in class.

Fig. 11. The public presentations of the Gen Z student sample in the real world.

The findings of this study help to understand the relationship between environmental realism and social presence in modifying public speaking anxiety among Gen Z learners. The high realism environments tend to evoke more anxiety than low realism environments. They may even create fear of public speaking, even in virtual spaces. In the context of VRET [51], the initial shock and sustained high heart rate variability observed in sessions P1 and P2 indicate activation of the fear network, a prerequisite for subsequent habituation and inhibitory learning, as evidenced by the P3 turning point. This transition from high variance SF pattern to more stable SC pattern underscores the efficacy of the Metaverse as a controlled domain for social skills training. Interestingly, the accelerated de-escalation of anxiety in low realism environments suggests that reduced anthropomorphism and environmental fidelity create lower anxiety. This allows participants to develop foundational skills in autonomic regulation and habituation in a safe space before being exposed to the high social evaluative pressure of realistic human avatars. Furthermore, the physiological stability and increased confidence achieved by week P4 indicate that repeated virtual immersion can effectively bridge the gap between digital isolation and real-world performance, particularly for Gen Z individuals whose baseline social anxiety is frequently exacerbated by digital immersion and fear of negative evaluation. By treating presence and realism as tunable variables, this research demonstrates that the Metaverse provides an ecologically valid yet psychologically safe laboratory for fostering long-term resilience against glossophobia.

V. Limitations and Future Research

To address the potential drawbacks identified in this study, particularly regarding the stress response observed during highly realistic simulations and the unpredictable nature of Q&A sessions, future research should adopt a more adaptive, longitudinal framework. While the current findings demonstrate that repeated practice sessions (P1–P4) began to induce habituation and physiological stability, a critical next step is to investigate the long-term retention of these gains to ensure that virtual success does not lead to an overreliance on simulated safety. Researchers should conduct follow-up assessments over 6 to 12 months to determine whether the reduced anxiety levels observed in Gen Z learners translate into sustained real-world performance or whether skill decay necessitates periodic virtual booster sessions. To mitigate the risk of unintended avoidance behaviors, future studies could implement dynamic exposure ladders that use real-time heart rate monitoring to automatically modulate environmental realism, ensuring that users are not prematurely exposed to high-pressure scenarios (RH_RR) before achieving stable heart rate patterns in lower-fidelity environments (FH_FR). Furthermore, to bridge the transferability gap caused by the unpredictability of human interaction, integrating Large Language Models (LLMs) into dynamic, AI-driven avatars could simulate authentic, varied Q&A sessions, thereby moving beyond pre-scripted content to better prepare students for spontaneous real-world evaluative pressure. Expanding measurement tools to include multimodal biofeedback, such as eye-tracking to monitor gaze avoidance or electrodermal activity to detect perspiration, would provide a more granular understanding of social anxiety beyond heart rate variability alone. Finally, the ethical implications of the Proteus Effect [54] should be explored to determine whether digital self-representation influences learners' self-efficacy and whether repeated exposure to highly realistic, human-like simulations has adverse psychological effects on a generation already prone to digital immersion and social isolation. This comprehensive future research will ensure that next-generation virtual exposure technology remains a potent, accessible, and highly adaptable intervention for addressing the pervasive fear of public speaking in contemporary education, ultimately reducing academic difficulties and improving the employability prospects of Gen Z students facing persistent social anxiety.

VI. Conclusion

In conclusion, this study demonstrates that audience and room characteristics, in terms of realism, can modulate perceived public speaking anxiety. Increasing audience and room realism directly impacts public speaking anxiety. This modulation appears to be related to the sense of presence, perceived realism, and the realism of participants' experiences within the virtual environment. The results demonstrate a robust correlation between anxiety scores, the sense of presence, and environmental realism. Physiological data indicated that arousal (heartbeat patterns) increased in tandem with the realism of the virtual room and audience. Notably, while increased presence intensified both psychological and physiological stress responses, the data also revealed a time-dependent mitigation of anxiety; as the duration of the presentation increased, participants showed a significant decrease in anxiety levels, indicating the efficacy of repeated practice within the simulation. These insights have practical implications for designing public speaking training for Gen Z students with public speaking phobias, using virtual reality in the Metaverse to facilitate gradual confidence and adaptation, and to enhance stress management and performance improvement in novice public speakers. Overall, the present results suggest the importance of studying both realism (avatar and room) and the duration of training of the properties of virtual environments. To adjust the anxiety of participants in exposure therapy or application in training for Gen Z students who experience social anxiety.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

S.N. conceptualized the research; S.N., L.P., S.C., and P.K. formulated a research hypothesis; S.N., L.P., S.C., and P.K. define the scope and objectives; S.N., L.P., S.C., and P.K. planned and method the research; S.N., L.P., S.C., and P.K. designed the research instruments; S.N., L.P., S.C., and P.K. conducted the research; S.N., L.P., S.C., and P.K. analyzed the data and the conclusion; S.N., L.P., S.C., and P.K. wrote the paper; all authors had approved the final version.

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