Research Square

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Enhancing Disaster Preparedness in Elementary Education through a 360 degree Virtual Tour to Improve Learning Outcomes and Behavioral Responses

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Abstract

Disaster preparedness education in elementary schools is often limited by a gap between declarative knowledge and actionable response behavior. Although immersive technologies show potential to bridge this divide, their adoption is constrained by accessibility, cognitive load, and limited empirical validation. This study examines the effectiveness of a scalable 360° virtual tour intervention in enhancing both cognitive and micro-behavioral aspects of disaster readiness among elementary students. A quasi-experimental non-equivalent groups pre-test–post-test design was conducted with 67 fifth-grade students across three intact classes. The intervention simulated evacuation scenarios through a classroom-based 360° virtual tour, emphasizing spatial awareness and risk-based decision-making. Preparedness was measured using an 11-item behavioral instrument assessing safety actions, maladaptive tendencies, and situational judgment. Results indicate a significant improvement in preparedness ($\Delta M = +6.16$, $p < .001$) with a very large effect size ($d = 1.91$). The strongest gains were observed in correcting high-risk behaviors, including unsafe evacuation responses and context-dependent decision errors ($d > 1.30$). In contrast, minimal improvement in foundational safety knowledge suggests ceiling effects, highlighting the intervention's role in strengthening behavioral certainty rather than basic understanding. Between-group differences were not significant ($F(2,64) = 0.38$, $p = .685$), indicating consistent effectiveness across contexts. These findings position 360° virtual tours as a pedagogically robust and cost-effective alternative to fully immersive VR, offering high ecological validity without substantial technological barriers. The study contributes empirical support for immersive disaster education and informs scalable disaster risk reduction strategies in primary education.

1. Introduction

Natural disasters present an escalating threat to communities globally, imposing profound challenges on infrastructure, economies, and human life [1]. Amid these growing climatic and geological risks, disaster preparedness education has emerged as a fundamental public health and safety imperative. Vulnerable populations like young children are disproportionately affected by emergencies due to their limited hazard recognition and dependency on adults during crises. Consequently, cultivating disaster readiness at the elementary school level is widely recognized as a critical strategy for building long-term community resilience. However, delivering effective disaster education to young learners presents a unique pedagogical challenge. Traditional instructional methods, such as textbook-based learning and routine physical drills, frequently lack the ecological validity required to simulate the unpredictable and dynamic nature of real-world emergencies. Furthermore, standard classroom instruction often fails to bridge the gap between theoretical knowledge and practical, situational application, leaving young students unprepared for the cognitive and emotional demands of an actual disaster [2].

To overcome the limitations of traditional instruction, educational frameworks have increasingly turned to immersive technologies. Tools such as Virtual Reality (VR) and augmented environments have demonstrated substantial potential to revolutionize experiential learning [3]. By simulating high-stakes scenarios in a safe, controlled environment, immersive systems allow learners to interact with complex

hazard simulations, thereby enhancing situational awareness, spatial cognition, and decision-making under pressure [4]. Recent interventions targeting senior high school and adult populations have successfully utilized VR to train individuals for specific threats, such as typhoon preparedness and hydrometeorological disasters [5]. However, fully rendered synthetic VR environments present significant barriers to entry for standard educational institutions. The reliance on expensive hardware, complex software development, and specialized training often renders these tools inaccessible for widespread K-12 implementation, particularly in under-resourced schools.

In response to these hardware and accessibility barriers, 360-degree video and virtual tours have emerged as a highly viable, cost-effective alternative. Unlike fully synthetic VR, 360-degree environments capture real-world settings, providing high visual fidelity and authenticity while remaining accessible via low-cost viewers or standard web browsers [6]. The integration of 360-degree virtual tours has gained notable traction in educational settings for facilities orientation, remote science laboratories, and cultural heritage education [7–8]. Studies indicate that 360-degree videos viewed immersively can inspire tangible behavioral changes and increase student engagement by effectively transporting the user to environments they cannot physically access [9–10]. Despite these advantages, the use of 360-degree virtual tours specifically designed for disaster preparedness remains an underexplored frontier.

A critical review of contemporary literature reveals a distinct demographic and methodological gap. While the pedagogical frameworks for immersive technology in K-12 education are expanding [11], empirical studies at the intersection of 360-degree media and hazard readiness are disproportionately skewed toward adult learners and higher education [12]. Existing studies concerning early childhood and elementary populations tend to focus merely on school adjustment or general engagement [13], rather than the acquisition of critical survival and safety protocols. Furthermore, much of the prevailing research relies on exploratory scoping reviews or post-intervention surveys, lacking the rigorous evaluation provided by multi-group quasi-experimental designs that measure tangible learning gains over time.

To address this notable void in the literature, the present study investigates the efficacy of a 360-degree virtual tour intervention for disaster preparedness among elementary school students. Utilizing a quasi-experimental, pre-test–post-test multiple-group design, this research evaluates how immersive, real-world visualizations of disaster scenarios impact students knowledge acquisition and situational readiness compared to conventional instructional methods. By targeting primary-aged learners, this study seeks to determine whether the high ecological validity of 360-degree media can effectively scaffold complex safety concepts without the cognitive overload often associated with fully synthetic VR environments. Ultimately, the findings of this study will contribute vital empirical evidence to the field of educational technology, offering scalable and practical guidelines for integrating immersive digital tools into K-12 disaster risk reduction curricula.

2. Literature Review and Thematic Synthesis

2.1. The Shift Toward Immersive Technologies in Education

The integration of immersive technologies into education reflects a broader shift from passive, two-dimensional instructional media toward experiential and context-rich learning environments. Recent literature indicates that immersive tools, ranging from fully computer-generated Virtual Reality (VR) to 360-degree video environments, enhance learner engagement, presence, and situational awareness compared to traditional formats [3, 10–11]. This shift is largely driven by the recognition that complex learning domains benefit from contextualized and interactive representations that approximate real-world conditions.

Within this spectrum, 360-degree video has emerged as a particularly promising modality due to its balance between realism and accessibility. Unlike fully synthetic VR environments, which often require high-end hardware and advanced development resources, 360° media captures real-world settings while remaining deployable through low-cost devices or web-based platforms [6]. However, despite its practical advantages, existing studies predominantly evaluate immersive technologies in terms of engagement and perceptual outcomes, with limited attention to their capacity to facilitate measurable behavioral change. This gap is particularly critical in domains where action-oriented responses are essential, such as disaster preparedness.

2.2. Disaster Preparedness Education: From Didactic to Experiential Approaches

Disaster preparedness education has traditionally relied on didactic instruction, static materials, and periodic physical drills. While these approaches provide foundational knowledge, they often fail to convey the dynamic, uncertain, and high-pressure nature of real hazard situations. As a result, learners may struggle to translate theoretical understanding into appropriate real-time responses.

Recent advancements have introduced immersive and simulation-based approaches to disaster education, including VR applications for typhoon preparedness and hydrometeorological hazard training [4–5]. These studies demonstrate that simulated environments can enhance hazard recognition and situational awareness by placing learners in realistic, high-stakes scenarios. However, such interventions are frequently designed for older learners or professional training contexts, where cognitive maturity and technological familiarity are assumed.

In contrast, research focusing on younger populations emphasizes the need for developmentally appropriate design. Studies in safety and environmental education indicate that overly complex or cognitively demanding simulations may overwhelm children, thereby reducing instructional effectiveness [2]. This suggests that while immersive approaches hold promise, their implementation in elementary education requires careful calibration of complexity, guidance, and pedagogical scaffolding.

2.3. Technology-Enhanced Learning in Elementary Contexts

The application of advanced technologies in elementary education introduces unique pedagogical challenges and opportunities. Young learners benefit from interactive and visually rich environments; however, their cognitive and metacognitive capacities necessitate structured guidance to ensure meaningful learning outcomes. Within this context, 360-degree virtual environments and web-based immersive tools have been successfully employed to simulate unfamiliar or inaccessible settings, such as virtual school tours or exploratory learning scenarios [8, 13].

These applications demonstrate that immersive media can reduce anxiety, enhance spatial understanding, and support experiential learning in a safe and controlled manner. Nevertheless, the literature consistently highlights that technological novelty alone does not guarantee learning effectiveness. Without intentional instructional design and teacher facilitation, students may focus on exploration at the expense of targeted learning objectives [10].

Moreover, most existing implementations in elementary settings are situated in low-risk or non-hazardous domains, such as cultural heritage or institutional orientation. Consequently, the potential of immersive technologies to support learning in high-risk, decision-critical contexts such as disaster preparedness remains insufficiently explored at the primary education level.

2.4. Limitations of Existing Immersive Interventions

Despite the growing body of research on immersive learning, several limitations constrain its applicability in formal education settings. A primary concern is accessibility. Fully computer-generated VR systems, while offering high levels of interactivity, often depend on specialized hardware and technical infrastructure, limiting their scalability in typical school environments [1]. This creates a disconnect between technological innovation and practical classroom implementation.

In response, 360-degree video and virtual tour-based approaches have been proposed as cost-effective alternatives that retain a degree of environmental realism while reducing technological barriers [9]. However, studies examining these approaches suggest that their effectiveness varies depending on factors such as interactivity, narrative structure, and user engagement [14]. Furthermore, existing research tends to prioritize user experience and perceived benefits rather than systematically measuring learning outcomes or behavioral changes.

Critically, there is a lack of rigorous experimental or quasi-experimental studies evaluating immersive interventions in authentic classroom contexts, particularly with younger learners. As a result, the extent to which these technologies contribute to sustained learning gains or actionable preparedness behaviors remains unclear.

3. Literature Analysis

A cross-cutting analysis of the literature reveals several structural imbalances and gaps.

First, methodologically, the field is dominated by exploratory studies, pilot implementations, and scoping reviews, with relatively few rigorous quasi-experimental designs employing pre-test and post-test measures in real educational settings. This limits the strength of causal inferences regarding the effectiveness of immersive interventions.

Second, population focus is heavily skewed toward higher education, vocational training, and adult learners [5, 12]. Elementary school students, despite being a critical demographic for early disaster preparedness are significantly underrepresented.

Third, in terms of technology, the literature prioritizes highly interactive, computer-generated VR systems, often overlooking more accessible alternatives such as 360-degree virtual tours. While the latter have been explored in educational contexts [7, 15], their application as a primary instructional tool for disaster preparedness remains marginal.

Finally, most studies emphasize cognitive and affective outcomes, such as knowledge acquisition and engagement, while giving limited attention to behavioral dimensions of learning. This is a notable limitation in disaster education, where effective response behaviors, such as decision-making, spatial navigation, and risk avoidance are critical indicators of preparedness.

4. Research Gap

Although immersive technologies have demonstrated considerable potential in enhancing learning experiences, their application in disaster preparedness education remains unevenly distributed across contexts and populations. Existing research predominantly focuses on fully immersive VR systems deployed in adult or secondary-level training environments, leaving elementary education comparatively underexplored. At the same time, disaster preparedness instruction for younger learners continues to rely largely on traditional, non-immersive approaches that inadequately represent the dynamic and situational nature of real hazards.

While 360-degree virtual tours offer a scalable and accessible form of immersive media, their use has largely been confined to low-risk educational applications such as virtual field trips and institutional orientation. Moreover, prior studies tend to prioritize engagement and knowledge acquisition, with limited emphasis on measurable behavioral outcomes that reflect actionable preparedness.

Consequently, there is a critical need to investigate how 360° virtual tour interventions can support not only cognitive learning but also micro-behavioral preparedness in elementary students. Addressing this gap through a rigorous quasi-experimental design will provide empirical evidence on the effectiveness of accessible immersive technologies in fostering both understanding and action-oriented readiness, thereby contributing to the advancement of disaster education in formal school settings.

5. Methodology

5.1. Research Design

This study employed a quasi-experimental non-equivalent groups pre-test–post-test design to evaluate the effectiveness of a 360° virtual tour intervention in enhancing disaster preparedness among elementary school students.

5.2. Participants

The participants consisted of 67 fifth-grade students from three intact classes (5A, 5B, and 5C) with age range of 10–12 years in an elementary school in Yogyakarta. The groups were comparable in age but differed in academic achievement and migration backgrounds. A non-random sampling approach was used due to institutional constraints.

5.3. Intervention

The intervention consisted of a 360° virtual tour simulating evacuation routes and safe zones within a school environment. The content was designed to promote spatial awareness and decision-making during emergency situations. The intervention was implemented using a classroom projector, through which the 360° virtual tour simulation was displayed to all students simultaneously. This approach facilitated a shared immersive learning experience while ensuring standardized delivery of the intervention across all participating classes.

5.4. Instruments

To measure students disaster preparedness, a structured questionnaire consisting of 11 items was developed. The instrument was designed to assess students behavioral intentions and decision-making responses in simulated disaster situations.

Each item represents a specific micro-behavioral action, such as seeking safety, following evacuation routes, or reacting to environmental cues. The items were contextualized to reflect realistic scenarios that students may encounter during a disaster event.

The instrument included the following behavioral indicators: Seeking guidance, avoidance of unsafe actions, safety-oriented decision making, passive or inappropriate responses, spatial awareness and evacuation behavior, recognition of safety signage. Responses were collected using a Likert scale, with higher scores indicating more appropriate disaster preparedness behavior.

The same instrument was administered as both a pre-test and post-test to evaluate changes in students preparedness following the intervention. Instrument details can be found in Appendix A.

5.5. Procedure

The study was conducted in three stages. First, students completed a pre-test to assess baseline disaster preparedness. Second, the 360° virtual tour intervention was implemented in separate sessions for each class to avoid interaction effects. Finally, a post-test was administered to measure learning gains.

6. Results and Findings

To ensure analytical rigor, the datasets were matched by student identifier, yielding a final sample of N = 67 matched pairs across the three non-equivalent groups (Class 5A: n = 21; Class 5B: n = 23; Class 5C: n = 23).

6.1. Data Preparation & Descriptive Statistics

Responses were mapped to a 5-point scale (Definitely = 5, Yes = 4, Maybe = 3, No = 2, Unlikely = 1). The seven items representing maladaptive/dangerous behaviors (Items 1, 2, 4, 5, 6, 8, and 9) were reverse-coded so that a higher score consistently indicates higher disaster preparedness.

Table 1
Descriptive Statistics by Group (Max Score = 55)

Group	N	Pre-Test M (SD)	Post-Test M (SD)	Gain M (SD)
Class 5A	21	42.43 (2.84)	48.33 (2.85)	5.90 (3.03)
Class 5B	23	41.61 (2.98)	47.52 (3.84)	5.91 (3.25)
Class 5C	23	40.52 (2.47)	47.17 (3.93)	6.65 (3.60)
Overall	67	41.49 (2.84)	47.66 (3.57)	6.16 (3.28)

Descriptive statistics indicated a substantial increase in mean scores from the pre-test (M = 41.49, SD = 2.84) to the post-test (M = 47.66, SD = 3.57) following the 360° virtual tour intervention. The overall mean gain across the combined sample was 6.16 points.

6.2. Inferential Statistics Results

Table 2
Within-Group Analysis (Paired Samples t-test)

Group	Mean Difference	t-value (df)	p-value	Cohen's d
Class 5A	+ 5.90	-8.93 (20)	< .001	2.08
Class 5B	+ 5.91	-8.74 (22)	< .001	1.72
Class 5C	+ 6.65	-8.86 (22)	< .001	2.03
Overall	+ 6.16	-15.39 (66)	< .001	1.91

Within-group analyses utilizing paired-sample t-tests revealed that the increase in disaster preparedness was statistically significant across all experimental cohorts (see Fig. 1). Class 5A demonstrated significant improvement ($t(20) = -8.93$, $p < .001$, $d = 2.08$), as did Class 5B ($t(22) = -8.74$, $p < .001$, $d = 1.72$) and Class 5C ($t(22) = -8.86$, $p < .001$, $d = 2.03$). Evaluating the overall sample yielded a massive effect size ($t(66) = -15.39$, $p < .001$, $d = 1.91$), indicating a profound behavioral knowledge acquisition and an increase in decision-making certainty

6.3. Between-Group Analysis (One-Way ANOVA)

To assess whether the intervention's efficacy differed by classroom environment, a one-way ANOVA was conducted on the gain scores. A one-way ANOVA on the gain scores revealed no significant difference between the three classes: $F(2, 64) = 0.38$, $p = .685$. The 360° virtual tour was equally effective across all experimental cohorts even with different background.

6.4. Item-Level / Behavioral Analysis

By utilizing the full 5-point spectrum, the results delivers that Q10 (going to the field from the toilet) shows a massive transformative effect, and Q2 (staying in class) jumped from a moderate to a large effect size. The overall Cohen's d increased from 1.79 to a staggering 1.91. This strongly indicates that the VR intervention didn't just change students from "Maybe" to "Yes", but transform a significant portion of them all the way from "Maybe" to "Definitely".

Table 3
Behavioral Item Analysis and Transformation Classification

Item (Abbreviated)	Behavioral Category	Mean Gain	t-value	p-value	Cohen's d	Impact Level
Q5. Run (Reverse)	High-Risk Evacuation	+ 1.63	-10.63	< .001	1.57	Transformative
Q10. Toilet to Field	Situational Evacuation	+ 1.27	-9.73	< .001	1.30	Transformative
Q2. Stay in Class (Rev)	Herd/Dependency	+ 0.69	-6.31	< .001	0.88	Large
Q1. To Teacher's Room (Rev)	Herd/Dependency	+ 0.66	-4.91	< .001	0.68	Moderate
Q6. Hide (Rev)	High-Risk Evacuation	+ 0.63	-4.61	< .001	0.65	Moderate
Q11. Follow Signs	Declarative Safety	+ 0.18	-3.46	.001	0.53	Moderate
Q3. Seek Safe Place	Declarative Safety	+ 0.19	-2.85	.006	0.43	Small
Q9. Follow Friends (Rev)	Herd/Dependency	+ 0.30	-2.70	.009	0.42	Small
Q7. Find Exit	Declarative Safety	+ 0.27	-2.21	.030	0.39	Small
Q4. Go to Highway (Rev)	Hazard Exposure	+ 0.28	-2.29	.025	0.28	Small
Q8. Do Nothing (Rev)	Hazard Exposure	+ 0.08	-0.93	.357	0.14	Small (Floor)

Item-level analysis (see Table 3 and Fig. 2) provided critical insights into specific behavioral shifts, particularly in how the intervention increased absolute certainty. The most transformative impacts were observed in the correction of high-risk evacuation protocols and situational contingencies. Specifically, the reduction in the maladaptive instinct to run yielded the highest gain (Mean Gain = 1.63, $p < .001$, $d = 1.57$), alongside a massive improvement in knowing to evacuate directly to the field rather than returning to class when isolated in a restroom (Mean Gain = 1.27, $p < .001$, $d = 1.30$). Furthermore, significant reductions were observed in herd dependency behaviors, such as the instinct to remain in the classroom (Mean Gain = 0.69, $p < .001$, $d = 0.88$). Conversely, basic declarative safety protocols, such as recognizing evacuation signs or avoiding doing nothing yielded minimal gains due to pronounced ceiling effects, as students entered the study already scoring highly on these foundational concepts.

7. Conclusion

This research demonstrates that 360° Virtual Tours (VT) are a transformative pedagogical tool capable of bridging the critical theory-practice gap in disaster education for young learners. The intervention achieved its most profound impact by correcting high-risk, maladaptive evacuation instincts, such as the impulse to run (Mean Gain = 1.63, d = 1.57) and the tendency to return to unsafe classroom environments when isolated (Mean Gain = 1.27, d = 1.30). While basic declarative safety knowledge showed minimal gains due to preexisting ceiling effects, the primary value of the 360° VT lies in its capacity to foster absolute behavioral certainty and situational decision-making areas where traditional rote-learning and physical drills often fall short.

These findings align with the broader scholarly consensus that immersive technologies are superior for hazard identification and risk perception in safety management [16]. By providing a safe, controlled environment to test critical life-saving decisions, this intervention successfully empowers students to practice survival strategies that would be too dangerous to simulate in real-world settings [1, 4]. Furthermore, the study's success with accessible VR viewers, such as Google Cardboard, highlights a scalable and democratized pathway for schools in resource-constrained regions to implement high-impact disaster risk reduction (DRR) programs [17].

The observed behavioral shifts also find theoretical support in the Technology Acceptance Model (TAM), where high perceived usefulness and psychological cognition are known to drive positive behavioral intentions [18]. In this context, the immersive nature of the 360° VT likely enhanced the students cognitive engagement, allowing them to internalize evacuation protocols more effectively than through conventional methods [5]. This approach represents a significant step toward building long-term community resilience by equipping the most vulnerable populations with the spatial awareness and critical thinking skills required to navigate unpredictable crises.

Despite these promising findings, the use of non-randomized groups and short-term post-testing limits causal generalization and long-term inference. Future research should focus on the longitudinal retention of these behavioral gains and explore the integration of multi-hazard scenarios (e.g., combining earthquakes with floods or fire). As climatic threats escalate, the shift from knowing what to do to knowing how to act with certainty is no longer just a pedagogical goal, it is a survival imperative.

Declarations

Ethical approval

Ethical approval for this study was obtained from the Research Ethics Committee of the Directorate of Research and Community Service, Universitas Negeri Yogyakarta (Approval No. T/1263/UN34.9/PT.01.04/2025). The approved protocol covers a series of educational research activities involving minimal-risk procedures conducted in school settings. Permission to conduct the study was also obtained from the participating school prior to data collection. All procedures performed in this study were carried out in accordance with institutional guidelines, national regulations, and the principles of the Declaration of Helsinki.

Consent to participate

Informed consent to participate was obtained from all participants' legal guardians prior to data collection. Assent was also obtained from the participating students. Participation was voluntary, and participants were informed of their right to withdraw at any time without penalty.

Consent to publish

Informed consent for publication of the study findings was obtained from all participants' legal guardians. No personally identifiable information is included in this manuscript.

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Author Contribution

SAH: Conceptualization, Methodology, Software, Investigation, Data Curation, Formal Analysis, Visualization, Writing - Original Draft, Writing – Review & Editing.PNA: Conceptualization, Methodology, Investigation, Formal Analysis, Funding Acquisition, Writing – Review & Editing.W: Methodology, Validation, Instrument Development, Investigation.SYA: Methodology, Validation, Instrument Development, Formal Analysis.TK: Resources, Supervision, Conceptual Guidance (Immersive Learning).S: Supervision, Validation.MBT: Supervision, Project Administration.P: Supervision, Resources, Investigation.All authors have read and approved the final manuscript.

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Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to ethical considerations involving minor participants but are available from the corresponding author on reasonable request.

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Figures

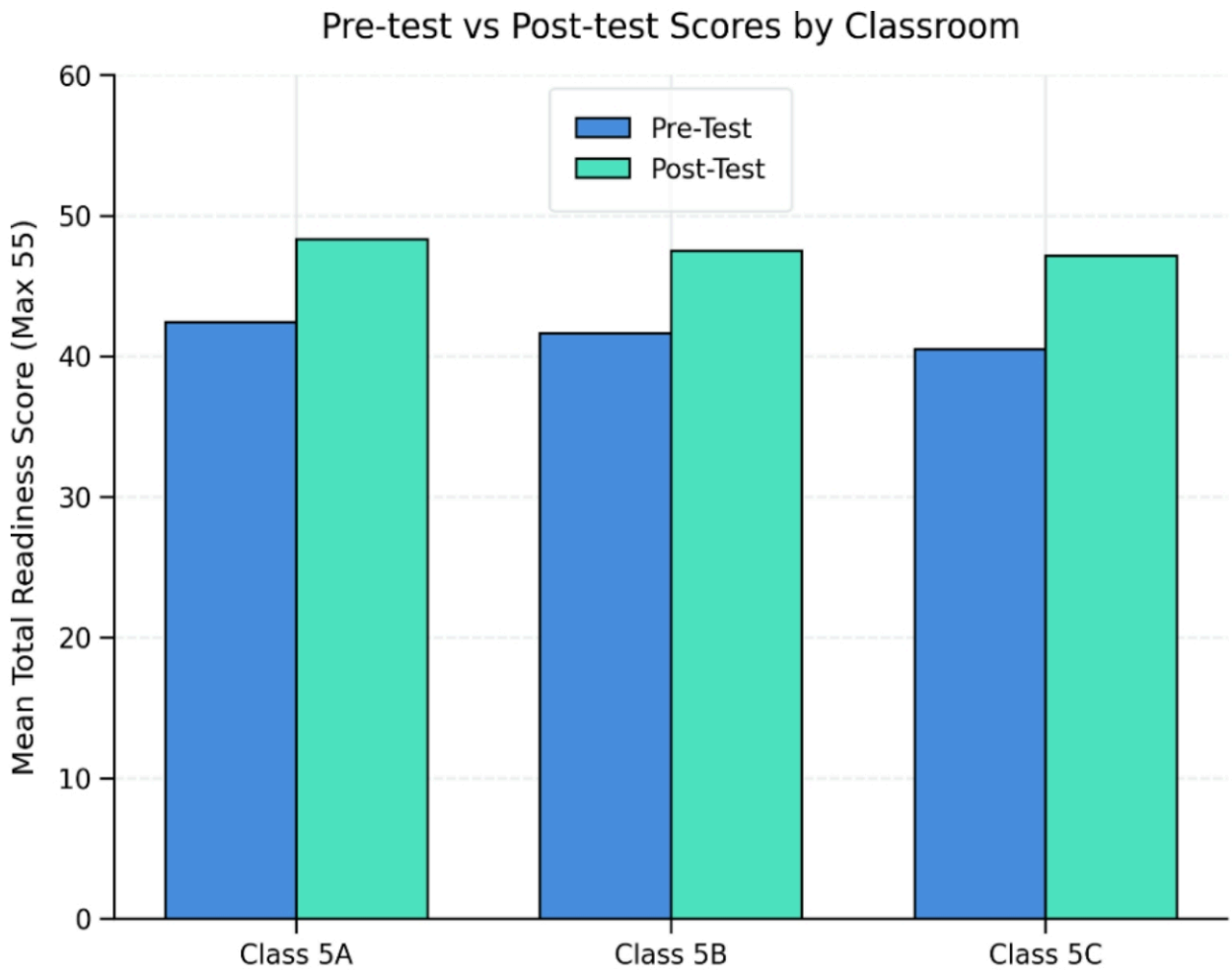


Figure 1

Pre- and Post-Intervention Disaster Readiness Scores

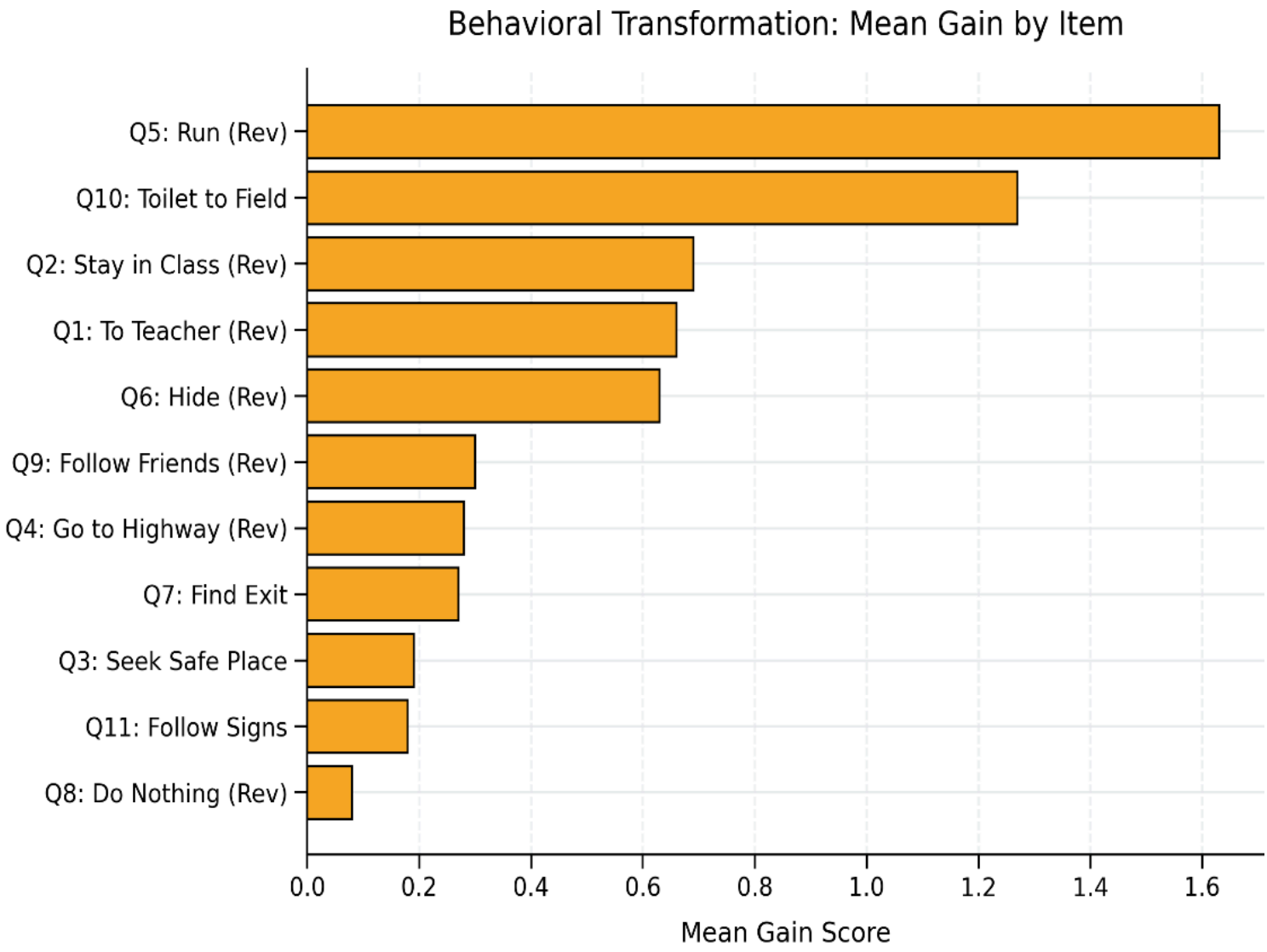


Figure 2

Item-Level Behavioral Gains

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- VTDataPostTestSup.csv
- VTDataPreTestSup.csv