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Immersive and Tangible VR Tool for Learning about Pre- and Post-Atomic Bombing Environments

Norio Setozaki
Nagasaki University, Japan
setozaki@nagasaki-u.ac.jp

Hayate Kitahara
Nagasaki University, Japan
bb52122311@ms.nagasaki-u.ac.jp

Fumito Kitamura
Nagasaki University, Japan
kitamuraf@nagasaki-u.ac.jp

Existing literature lacks tools that combine spatial, multisensory exploration with historically grounded, learner-centered content to foster a deeper understanding of pre- and post-atomic bombing environments. Therefore, this study introduces an immersive, tangible virtual reality (VR)-based educational tool designed to facilitate exploratory learning about Nagasaki's environment before and after the atomic bombing. The system integrates tangible user interfaces with VR, enabling learners to build virtual cityscapes by arranging physical building models. Learners can transition between pre- and post-atomic bombing environments to explore detailed visualizations enhanced by sound, animation, and multimedia. A user study involving university students revealed that the VR tool increased interest in peace-related topics, especially post-bombing history, and improved engagement and concentration. Comparative analysis indicated that the VR environment was more effective than a 2D digital map in conveying the atmosphere of the pre- and post-bombing settings and supporting historical understanding. These findings suggest that immersive, tangible VR is a valuable medium for peace education, fostering experiential and emotional engagement with historical content.

Keywords: VR, TUIs, Peace Education, Atomic Bombing, Immersive Learning

Introduction

As Japan approaches the 80th anniversary of the end of World War II, the aging of the atomic bombing survivors (hibakusha) has led to a steady decline in their numbers (Ministry of Health, Labour and Welfare, 2024). Consequently, the direct transmission of their experiences is becoming increasingly challenging. In this context, there is a growing need to explore new approaches to peace education, particularly through the effective use of information and communication technologies (ICT) such as virtual reality (VR).

With the rapid advancement and accessibility of ICT, VR technologies enabling immersive and experiential learning have become more feasible for educational purposes. VR can foster learners' curiosity and enhance their understanding of complex historical and social issues by providing simulated environments (Zhigeng et al., 2006) while supporting inquiry-based learning by encouraging learners to actively identify and resolve problems (Sato et al., 2012).

VR technologies have been recognized as powerful tools for enhancing the understanding of war and humanitarian crises within the framework of peace education. Through visually rich and emotionally engaging experiences, learners can concretize abstract concepts. This educational potential of VR can be theoretically grounded in experiential learning theory (Kolb, 1984), which emphasizes the role of concrete experience and reflective observation in knowledge construction. Similarly, constructivist perspectives suggest that learners build understanding through active exploration and contextual interaction, both of which are facilitated by immersive VR environments. In the context of historical and peace education, the ability to adopt others' perspectives and engage emotionally is considered essential for promoting deeper conceptual understanding and empathy. Thus, the use of immersive environments is not merely a technical enhancement, but a pedagogically grounded approach to fostering reflective and transformative learning.

Dragicevic (2022) emphasized the potential of VR to convey the reality of distant or underrepresented humanitarian issues by combining quantitative data, qualitative narratives, and emotional immersion to promote a comprehensive understanding. In a systematic review, Paananen et al. (2022) reported that extended reality environments enable users to adopt others' perspectives and foster empathy. Similarly, Yong et al. (2024) demonstrated that a VR-based retrospective embodied perspective-taking system enhanced communication skills and emotional responses in conflict scenarios by reducing attribution bias and encouraging cooperative attitudes. Gregory (2020) further proposed the application of VR in conflict mediation as a means to foster dialogue and mutual understanding among stakeholders by enabling them to "understand conflict consequences on non-combatants," "adopt different perspectives," and "learn lessons from other conflicts."

Several case studies in Japan have explored the application of VR in peace education. For instance, the Nagasaki Archive (Watanabe et al., 2011) integrates user-contributed and archival data into geospatial maps. Moreover, several omnidirectional panoramic VR teaching materials have been developed. Setozaki and Nagahama (2017) designed panoramic VR content that presented victim and perpetrator perspectives, promoting multi-perspective thinking. Their studies revealed that VR-based experiential learning contributed to knowledge retention comparable to that achieved through traditional note-taking (Setozaki et al., 2017). Other studies have investigated VR systems designed to bridge the past and present (Fujiki et al., 2013) and foster empathy from global perspectives (Fujiki et al., 2020).

VR systems are primarily built upon pre-constructed virtual environments; however, Watanabe (2024) emphasized the importance of interaction within real-world contexts, highlighting the potential of real-environment-based interaction to elicit immersive "flow" states and facilitate multidimensional learning. However, conventional VR content is often disconnected from learners' real-world experiences because most environments are passively received from content creators.

Therefore, this study focuses on tangible user interfaces (TUIs) that allow learners to actively build and manipulate virtual environments through direct interactions with physical models in the real world. TUIs eliminate the need for complex CG modeling or programming, enabling the intuitive construction of virtual spaces. TUIs facilitate seamless interaction between physical and digital elements (Ishii & Ullmer, 1997), making them well-suited for promoting engagement, conceptual understanding, and learner motivation (Tselegkaridis et al., 2024). Gallud et al. (2022), in their systematic mapping study of TUI applications in early and K-12 education, highlighted several pedagogical advantages: TUIs promote engagement in educational activities, support enjoyable learning, and foster collaboration among learners—all valuable elements for peace education.

Setozaki et al. (2021) developed a prototype of an immersive TUI-based VR educational tool for peace learning. A preliminary evaluation with university students indicated increased interest and active participation. However, the system was limited to pre-bombing environments and lacked sufficient informational depth. In the previous version of the system, information about the daily lives of people before and after the atomic bombing, as well as the actual damage caused, was not sufficiently presented. As a result, learners may have struggled to engage in exploratory learning or develop the motivation to deepen their knowledge. In other words, simply reproducing pre- and post-atomic bombing environments in a virtual setting may leave learners uncertain about what they are expected to learn, and thus prevent them from engaging in deeper reflection on peace.

In this study, we designed and developed an immersive, tangible VR-based educational tool for exploring pre- and post-atomic bombing environments. Based on interviews with peace education experts, we identified the types of information to be included in the virtual environments. The developed system allows learners to experience immersive representations of pre- and post-atomic bombing conditions. Individual questionnaire-based evaluations were conducted to assess the tool's educational benefits and the effectiveness of exploratory learning within the virtual environment. To more clearly assess the educational impact of the system, we compared the immersive virtual environment with a non-immersive 2D digital map. This comparative approach enabled us to examine how spatial and bodily immersion contributes to emotional understanding and reflective thinking in peace education, and to explore the educational significance of these differences in contrast to 2D representations.

In light of these objectives, the aim of this study was to develop and evaluate an immersive, tangible VR-based educational tool that enables learners to explore and compare pre- and post-atomic-bombing environments. To investigate the educational potential of this tool, we addressed the following research questions:
RQ1: How can an immersive, tangible VR-based educational tool be designed to effectively present pre- and post-atomic-bombing contexts for peace education?
RQ2: What are the perceived educational benefits of the VR-based learning tool, as reported through individual subjective evaluations?
RQ3: How does exploratory activity in the immersive virtual environment affect learners' engagement, understanding, and reflective thinking, compared to interaction with a non-immersive 2D digital map

Development of the Immersive, Tangible VR-Based Educational Tool

Overview of the VR Learning Tool

Figure 1 illustrates an overview of the educational tool. Learners reconstructed the cityscape of Shiroyama in Nagasaki as it appeared before the atomic bombing by placing physical building models on a tabletop. The spatial positions of these models were recognized in real time using markers attached to their bases, enabling the generation of a corresponding virtual environment. A webcam placed beneath the table detected these markers. The marker recognition method was based on the tangible systems developed by Morita and Setozaki (2017) and Setozaki et al. (2021).

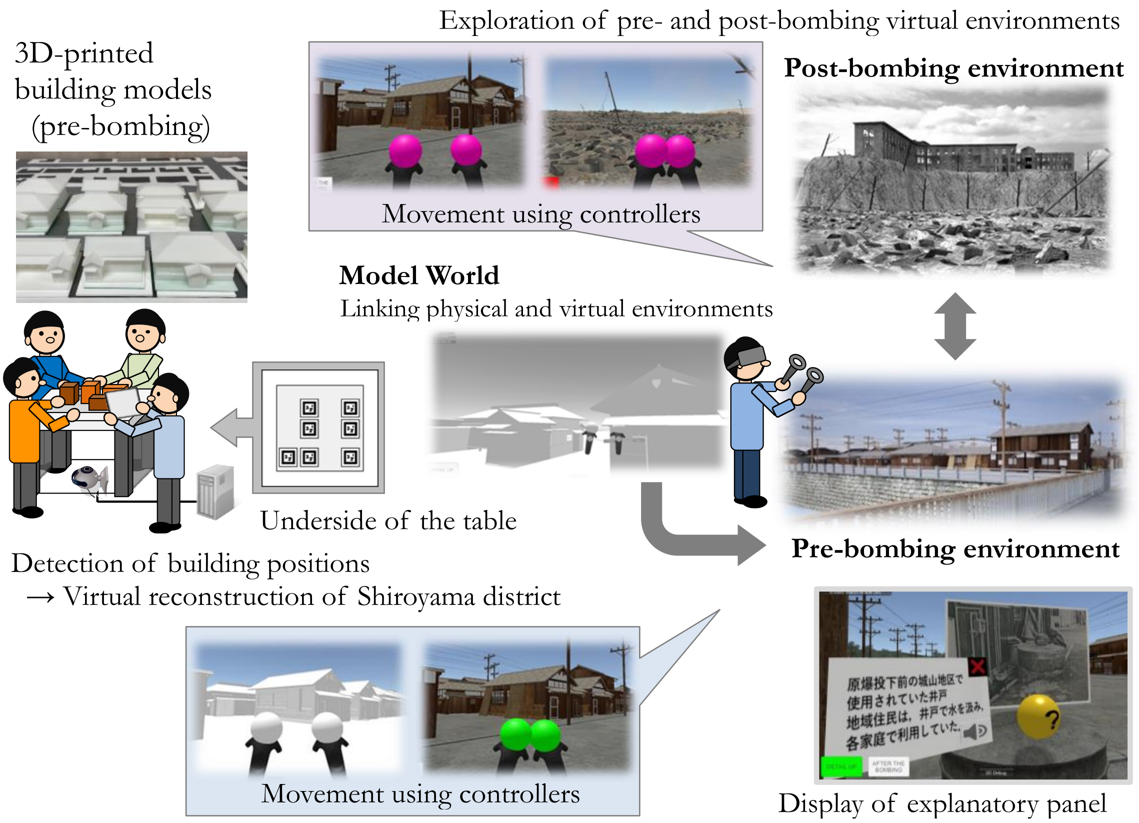
In earlier systems, fluorescent lights were installed at two positions under the table; however, their recognition rates were inconsistent. Therefore, we compared the recognition rates between the 4 cm and 6 cm square markers and between configurations with two fluorescent lights and four LED lights. The combination of 6 cm square markers and four LED lights achieved a 100% recognition rate across 20 trials for each condition (Table 1). Based on these results, this configuration was adopted for the proposed system.

Learners wore a head-mounted display (HMD) to immerse themselves in the "model world"—a virtual environment generated from the physical models. This model world used the same color scheme (white) as the real-world models, enabling learners to intuitively recognize the correlation between the physical and virtual elements.

Learners could transition to a detailed virtual environment representing the pre-bombing period by combining the two virtual spheres displayed at the ends of handheld controllers. This environment featured detailed representations of water pipes, signage, plants, and buildings, such as shops and community centers, based on historical references. Additional elements, such as bridges, wells, stone-paved roads, and rivers, were included, along with animated human figures, to depict daily life. Environmental sounds were also incorporated to enrich the auditory experience.

Learners pressed the trigger buttons on the controllers to combine the two virtual spheres and transition to the post-

Figure 1.
Overview of the Immersive Tangible VR Tool



bombing environment. This transition was presented using a whiteout visual effect. The post-bombing environment, reconstructed from photographs and historical records, depicted scenes of rubble and debris scattered throughout the area. Streets and block boundaries were indistinguishable, while trees and utility poles appeared distorted by heat. The environment was covered in gray dust and scorch marks, devoid of signs of daily life. Wind sounds were added to convey the silence and desolation of the post-bombing setting and enhance immersion.

The pre- and post-bombing virtual environments included floating golden spheres marked with question marks to indicate areas containing supplementary information. These spheres featured reflective textures and animations such as vertical floating and slow horizontal rotation to ensure visibility from various angles. When selected using the controller, related images and textual explanations were displayed. The text appeared in a movable panel linked to the learner's left-hand controller and could be hidden by tapping an "×" button using the right-hand controller. Additionally, an audio button allowed learners to toggle voice narration of the same content on or off.

Table 1.
Recognition Accuracy of 4 cm and 6 cm Markers Under Different Lighting Conditions

Condition	Mean Number of Recognitions (Standard Deviation)	Mean Recognition Rate (%) (Standard Deviation)
4 cm Marker (Fluorescent Light)	9.1 (1.81)	56.9 % (11.34)
6 cm Marker (Fluorescent Light)	8.6 (3.40)	53.8 % (21.23)
4 cm Marker (LED Light)	15.9 (0.36)	99.1 % (2.23)
6 cm Marker (LED Light)	16.0 (0.00)	100.0 % (0.00)

Information Design in the Virtual Environment

Semi-structured interviews were conducted with five individuals engaged in peace education to determine the types of information to include in the virtual environment. These individuals included three university faculty members with experience in developing VR content for peace education: one specializing in nuclear disarmament and abolition, one in education and ICT-based peace learning, and one in engineering. The remaining two participants were staff members from the Nagasaki National Peace Memorial Hall for the Atomic Bomb Victims and the Nagasaki City Atomic Bomb Legacy Promotion Division. Each interview lasted approximately 45 min and covered the following topics: key considerations in developing peace education materials, strategies for fostering personal engagement among learners, suggestions for additional images and textual content, and desired learning experiences for children. The authors reviewed and categorized the responses.

A key design priority identified from the interview was "maintaining learners' interest. " In response, the system incorporated interactive floating spheres marked with question marks to guide learners to supplementary content. Furthermore, a "stimulus-conscious design" approach was adopted to minimize emotional distress, avoiding depictions of human suffering and focusing on structural damage to buildings.

In the pre-bombing environment, one priority was presenting explanations that provided a "shared frame of reference," helping bridge generational and cultural gaps by contextualizing historical elements unfamiliar to modern learners. Examples include the use of wells and the transport of tin roofs. Another design element was "highlighting commonalities with present-day learners," such as depicting children shopping at local stores or participating in school sports events. Furthermore, under the category of "depicting daily life at the time," the system presented scenes such as family photos and shared meals to help learners visualize the everyday experiences of people living before the bombing.

In the post-bombing environment, "objective facts" were presented through images of destroyed schools and collapsed buildings. Under the category "Visual Measures of Impact," artifacts such as melted glass bottles and clothing with embedded glass shards were displayed to illustrate the magnitude of the destruction. Under the category "Scenes of People After the Bombing," images depicted residents carrying debris and individuals walking through the burned-out ruins following their visit to the site. Under the category "Comparison of Pre- and Post-Bombing Conditions," before-and-after photographs of school buildings and other landmarks were included to visually illustrate the destruction caused by the atomic bombing. Additionally, under "Application of Multimedia Techniques," AI-colorized images of pre- and post-bombing scenes were presented to enhance the realism and emotional engagement of the visual materials.

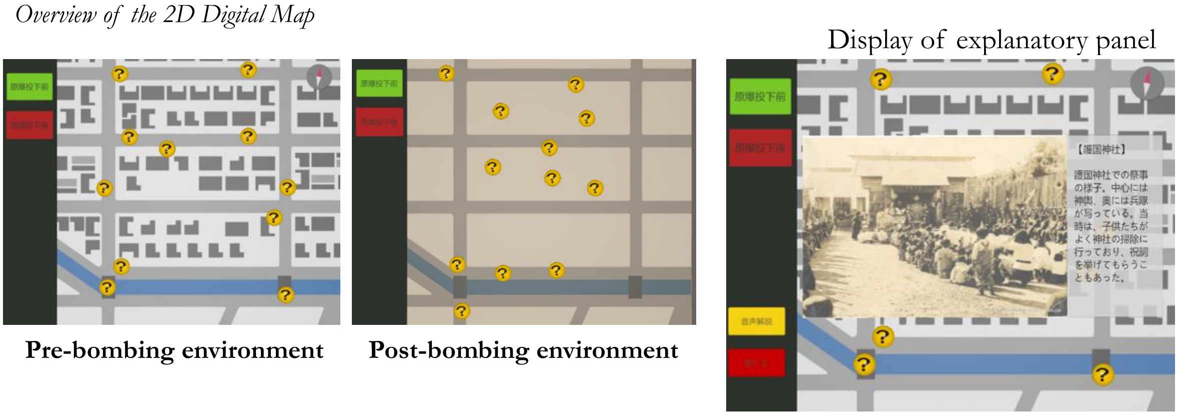
The interviews also provided broader considerations for instructional design, including leaving room for interpretation, incorporating inquiry-based prompts, adapting content to learner age, conducting on-site learning, encouraging dialogue, and incorporating survivor narratives. These elements are important for designing effective learning experiences using the tool, although not directly related to the VR content.

Development of a 2D Digital Map

We developed a simplified 2D digital map, excluding the exploration functionality of the VR environment, to evaluate the learning impact of the immersive VR tool (Figure 2). This map presents pre- and post-bombing photographs, textual descriptions, and audio explanations via a tablet interface. Instead of using HMDs, learners accessed content by tapping question-mark spheres on the map.

Similar to the VR environment, the system allowed users to switch between the pre- and post-bombing maps using buttons in the upper-left corner. The content—including the images, text, and audio—was identical to that used in the VR version.

Figure 2.
Overview of the 2D Digital Map



Evaluation Method

This study included 19 university and graduate students. Participants worked in small groups of 2–4 and engaged in a 40-min session using the educational tool. The usable physical area for VR activity was set to 2.0 m × 3.0 m. After receiving instructions and providing informed consent, participants were introduced to the context of peace education and trained on how to use the tool.

Participants first reconstructed the cityscape of pre-bombing Nagasaki using 2D digital maps and physical models. The groups discussed and positioned the models for approximately 10 min. Each participant then engaged in a solo VR exploration session for approximately 10 min using the HMD while the rest of the group observed and provided commentary via a secondary monitor.

After the sessions, the participants completed a questionnaire evaluating the following aspects: general impressions of the activity (seven items); assessments of visual, textual, and audio content (12 items); model placement activity using the 2D digital map (nine items); exploration in the VR environment (nine items). For the first two categories, responses were classified as either positive (strongly agree or agree) or negative (disagree or strongly disagree) and analyzed using two-tailed exact binomial tests to assess statistical significance. Responses were scored on a 4-point Likert scale for the latter two categories and analyzed using paired t-tests to compare participants' evaluations across different conditions.

Results and Discussion

General Evaluation of the Activities

All participants responded positively to the item "The learning material was interesting," indicating strong engagement (Table 2). Items such as "My interest in peace learning increased," "I became more interested in Nagasaki after the bombing," and "I wanted to learn more about the lives of people after the bombing" received statistically significant positive responses at the 1% level. The items "I became interested in learning more about World War II" and "I wanted to learn more about Nagasaki before the atomic bombing" received a significantly higher number of positive responses at the 5% level, suggesting that the tool promoted broader historical curiosity beyond the immediate post-bombing context. However, no significant difference was observed for the item "I wanted to learn more about life before the bombing," suggesting that the pre-bombing content was less impactful.

These results suggest that while the VR tool effectively fostered interest in post-bombing history and peace-related issues, its impact on learners' understanding of pre-bombing life and culture was comparatively limited, indicating potential areas for content enhancement.

Table 2.
Questionnaire Results on Overall Learning Activities

Question item	Positive responses	Negative responses	Results (Fisher's exact test)	Strongly agree	Agree	Disagree	Strongly disagree
The learning material was interesting	19	0	**	17	2	0	0
My interest in peace learning increased	17	2	**	8	9	2	0
I became more interested in Nagasaki after the bombing	17	2	**	10	7	2	0
I wanted to learn more about the lives of people after the bombing	16	3	**	10	6	3	0
I became interested in learning more about World War II	15	4	*	7	8	4	0
I wanted to learn more about Nagasaki before the atomic bombing	15	4	*	7	8	3	1
I wanted to learn more about life before the bombing	13	6	*n.s.*	7	6	6	0

**: p<.01, *: p<.05 *n.s.*:not significant

Evaluation of Explanatory Content: Photographs, Text, and Audio

Table 3 presents the results of the questionnaire regarding the photographs, text, and audio explanations. All participants responded positively to the item "The system was easy to operate," suggesting that the VR tool's intuitive interface was effective. Interactive elements such as floating question-mark spheres also contributed to usability by guiding user interactions. Items such as "I felt the impact of the atomic bombing, " "Colorized photos made it easier to imagine life at that time compared to monochrome photos, " "I was able to compare the pre- and post-atomic bombing environments," and "I thought about peace from my perspective" all received significantly positive responses at the 1% level. These findings indicate that the visual elements in the VR environment successfully promoted interest and reflective thinking. Particularly, the comparison of the same locations before and after the bombing and the use of AI-colorized photographs helped learners visualize historical changes and enhanced their emotional engagement and imagination. Moreover, the items "I made new discoveries" and "I learned about things that are no longer commonly used" received significant positive responses at the 1% level. Content describing daily life in the past, such as the transport of tin roofs and the use of wells, provided intellectually stimulating contrasts with contemporary lifestyles. Additionally, the item "I felt a connection to life before the bombing" received significantly positive responses at the 5% level, suggesting that content highlighting commonalities with learners—such as school sports festivals or shopping at local stores—supported empathy and a sense of familiarity with the people of the past.

In contrast, no significant difference was observed for the item "I saw similarities between life before the bombing and the present," indicating that the information presented may not have included enough clearly relatable elements to modern life. Participants' interpretations may have also varied depending on their backgrounds and experiences.

Table 3.
Questionnaire Results on Explanatory Content (Images, Audio, and Text)

Question item	Positive responses	Negative responses	Results (Fisher's exact test)	Strongly agree	Agree	Disagree	Strongly disagree
The system was easy to operate	19	0	**	10	9	0	0
I felt the impact of the atomic bombing	18	1	**	11	7	0	1
Colorized photos made it easier to imagine life at that time compared to monochrome photos	18	1	**	10	8	1	0
I was able to compare the pre- and post-atomic bombing environments	18	1	**	9	9	1	0
I thought about peace from my own perspective	17	2	**	4	13	2	0
I made new discoveries	16	3	**	9	7	3	0
I learned about things that are no longer commonly used	16	3	**	9	7	3	0
I felt a connection to life before the bombing	14	5	*	4	10	5	0
I saw similarities between life before the bombing and the present	12	7	*n.s.*	3	9	7	0
I felt fear when looking at post-bombing photographs	11	8	*n.s.*	5	6	3	5
I thought scientifically about the damage caused by the atomic bombing	8	11	*n.s.*	4	4	8	3
I felt that opinions were forced upon me	4	15	*	4	0	5	10

**: p<.01, *: p<.05 *n.s.*:not significant

Similarly, the items "I felt fear when looking at post-bombing photographs" and "I thought scientifically about the damage caused by the atomic bombing" indicated no significant differences between positive and negative responses, possibly attributed to the design of the VR environment, which intentionally avoided depictions of human suffering and instead emphasized objective material evidence, such as destroyed buildings and melted bottles. Furthermore, the lack of scientific explanation may have limited participants' ability to evaluate damage analytically. Finally, the item "I felt that opinions were forced upon me" received significantly more negative responses, indicating that participants perceived the content as neutral and non-coercive. This observation suggests that the tool allowed learners to explore the content autonomously, thus encouraging independent thought and interpretation.

In summary, the explanatory content—through visual comparisons, representations of daily life, and a non-directive presentation of information—effectively fostered learners' historical understanding and reflective thinking about peace. However, improvements could be made by linking the content directly to contemporary life and integrating scientific perspectives.

Comparison Between the 2D Digital Map and the Virtual Environment

Figure 3 presents the results of the questionnaire comparing the model placement activity using the 2D digital map and the exploratory activity in the virtual environment. Table 4 presents the mean and standard deviation for each item. All the participants responded positively to the items "I participated actively" and "I was focused during the activity" for both modes, suggesting that both activities encouraged learner engagement. However, the item "I was focused during the activity" received significantly higher ratings for the VR environment ($t(18) = 2.51$, $p < .05$, *Cohen's* $d = 0.59$), indicating that its immersive nature may have enhanced learner concentration. The visual and spatial elements of the VR environment possibly helped capture and maintain their attention.

The items "I learned about the realities of the atomic bombing" and "I was able to understand the atomic bombing objectively" also received significantly higher scores in the VR condition, with differences of over one point compared to the 2D digital map ($t(18) = 5.01$, $p < .01$, *Cohen's* $d = 1.18$, $t(18) = 4.61$, $p < .01$, *Cohen's* $d = 1.09$). This finding suggests that the immersive and spatially rich representation in VR helped the participants grasp the impact of the bombing more concretely and better deeper understand its consequences.

Figure 3.
Comparison of Evaluation Results Between the 2D Digital Map and the Virtual Environment

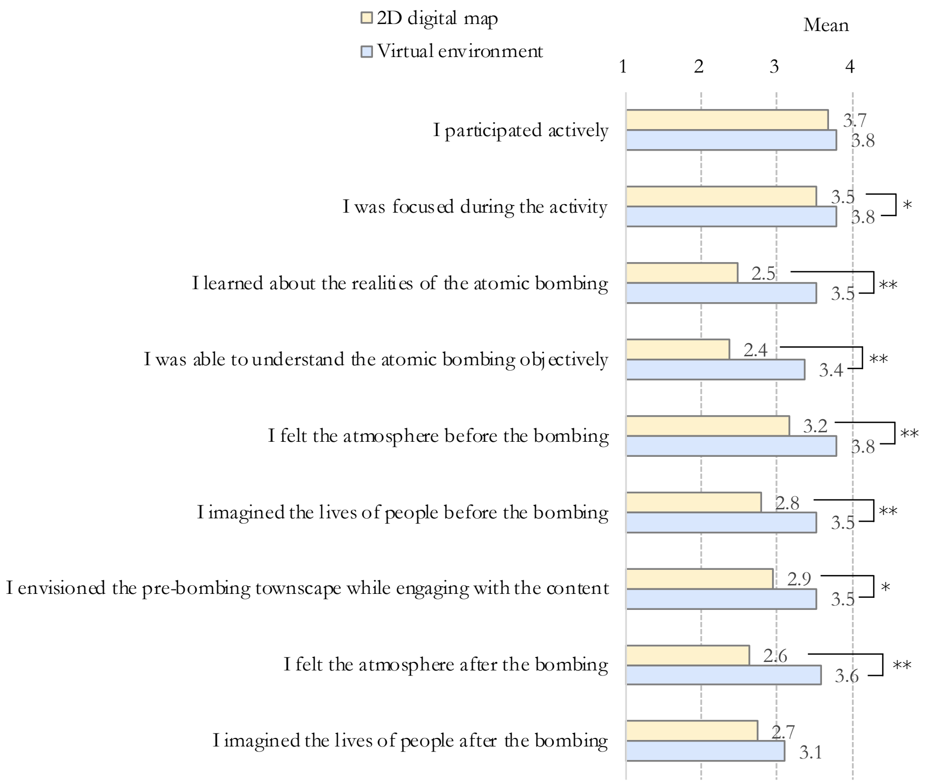


Table 4.
Learner Responses in 2D Digital Map and VR Conditions (M ± SD)

Question item	2D Digital Map (M ± SD)	Virtual Environment (M ± SD)
I participated actively	3.7 ± 0.46	3.8 ± 0.41
I was focused during the activity	3.5 ± 0.50	3.8 ± 0.41
I learned about the realities of the atomic bombing	2.5 ± 0.60	3.5 ± 0.75
I was able to understand the atomic bombing objectively	2.4 ± 0.74	3.4 ± 0.58
I felt the atmosphere before the bombing	3.2 ± 0.74	3.8 ± 0.41
I imagined the lives of people before the bombing	2.8 ± 0.69	3.5 ± 0.60
I envisioned the pre-bombing townscape while engaging with the content	2.9 ± 0.83	3.5 ± 0.50
I felt the atmosphere after the bombing	2.6 ± 0.93	3.6 ± 0.75
I imagined the lives of people after the bombing	2.7 ± 1.07	3.1 ± 0.91

N=19

Similarly, items such as "I felt the atmosphere before the bombing," "I imagined the lives of people before the bombing," and "I envisioned the pre-bombing townscape while engaging with the content" received significantly higher ratings for the VR environment ($t(18) = 3.07$, $p < .01$, *Cohen's* $d = 0.72$, $t(18) = 3.08$, $p < .01$, *Cohen's* $d = 0.73$, $t(18) = 2.37$, $p < .05$, *Cohen's* $d = 0.56$). Simulating everyday life scenes in the virtual environment appears to have supported the participants in intuitively imagining life and urban spaces before the bombing.

The item "I felt the atmosphere after the bombing" also received significantly higher ratings for the VR condition ($t(18) = 4.03$, $p < .01$, *Cohen's* $d = 0.95$), indicating that the VR environment effectively conveyed the post-bombing landscape and atmosphere, leaving a strong impression on the participants. The immersive experience allowed learners to perceive the desolate conditions more vividly and understand the post-bombing context.

However, no significant difference was observed for the item "I imagined the lives of people after the bombing" ($t(18) = 1.60$, *n.s.*, *Cohen's d* = 0.38), suggesting that both environments may have lacked sufficient detail to enable participants to visualize post-bombing life and that the content may not have included enough representations of everyday human activity in the aftermath.

Overall, the immersive, tangible VR tool enhanced learner engagement and concentration, facilitating an understanding of the atomic bombing and pre-war society. The VR environment supported the visualization of pre-bombing life and atmosphere; however, its ability to convey post-bombing human experiences appears limited.

The findings suggest that the immersive VR environment effectively enhanced learners' interest and understanding, particularly in relation to post-bombing scenes and peace-related issues. This tendency may be interpreted through experiential learning theory (Kolb, 1984), which emphasizes the role of concrete experience and emotional engagement in fostering reflection and conceptual change. The post-bombing environments, which presented stark visual contrasts and emotionally charged imagery, likely supported more vivid and memorable learning experiences, facilitating empathy and reflective thinking.

By contrast, scenes depicting pre-bombing life exhibited more limited effects in generating learner interest or deep reflection. Although visual reconstructions of pre-war streets and daily activities were included, the content may have lacked sufficient narrative cues or emotional salience to help learners meaningfully connect with that period. Similarly, in the case of post-bombing life, the environments focused mainly on physical destruction and did not fully portray how civilians lived during the recovery phase, which may have limited the learners' ability to imagine daily life in the aftermath.

These findings highlight a key pedagogical insight: Immersive learning environments are most effective when they are not only visually engaging but also contextually and emotionally rich. To better support historical and peace education, future content development should consider incorporating personal stories, sensory details, and emotionally resonant elements that help learners connect with both the ordinary and extraordinary aspects of historical experience.

Conclusion

This study aimed to design and evaluate an immersive, tangible VR-based educational tool that enables learners to explore and compare pre- and post-atomic bombing environments. Integrating TUIs with immersive VR allowed learners to construct virtual cityscapes using physical models and experience historical transitions through multisensory, interactive exploration. Based on interviews with experts in peace education, the virtual environments were designed to include historically grounded and pedagogically relevant content, including visual comparisons, contextual explanations, and multimedia-enhanced materials.

The user study with university and graduate students demonstrated that the tool promoted interest in peace-related issues, particularly those concerning the post-bombing context. The learners expressed increased curiosity about the history of Nagasaki and the lives of its people post-bombing. The immersive nature of the virtual environment significantly enhanced engagement, concentration, and emotional involvement, particularly in conveying the atmosphere and the impact of the bombing. Furthermore, integrating explanatory content—such as photographs, textual descriptions, and audio narratives—fostered reflective thinking and historical understanding while maintaining neutrality and avoiding prescriptive messaging.

A comparative analysis between the immersive VR environment and a 2D digital map revealed that the VR environment was more effective in helping learners imagine pre-bombing life and comprehend the physical consequences of the atomic bombing. However, both environments were limited in conveying the post-bombing lives of civilians, suggesting the need for richer representations of human activity in the aftermath. Additionally, although the tool successfully fostered empathy and curiosity, its ability to evoke interest in pre-bombing daily life was relatively limited, indicating areas for future improvement in content design and narrative structure.

This study builds upon the earlier work of Setozaki et al. (2021), which focused exclusively on virtual representations of pre-bombing environments, by extending the immersive VR system to include post-bombing scenes. This expansion enhanced the system's visual and emotional impact, enabling a more powerful depiction of the aftermath. Additionally, by integrating information based on interviews with peace education experts, the system effectively encouraged learners to engage in exploratory learning and increased their motivation to acquire further knowledge. The comparative analysis with a non-immersive 2D digital map further revealed that spatial and visual representations in immersive VR enabled learners to experience the devastated post-bombing environment more vividly and emotionally.

Beyond this functional enhancement, this study contributes theoretically by situating immersive learning within the framework of experiential and affective learning theories, highlighting how embodied virtual exploration fosters emotional engagement and reflective thinking. Methodologically, the inclusion of a comparative analysis using a non-immersive 2D digital map enables a more nuanced evaluation of the role of spatial immersion in peace education.

However, the comparison between the 2D digital map and the immersive VR environment was not strictly controlled. Differences in the nature of activities—physical model placement vs. virtual exploration—and potential order effects may have influenced the outcomes. Therefore, the findings of this study should be interpreted as exploratory and limited in scope. Further research is needed to continue evaluating the educational effects of immersive virtual environments and investigate the pedagogical impact of the model placement activity.

Future research should explore the application of this tool in formal educational settings with younger learners, such as primary and secondary school students, to evaluate its effectiveness across different age groups. Moreover, expanding the content to include scientifically grounded explanations of the effect of the bombing, as well as personal narratives and testimonies, may deepen learners' understanding and emotional engagement. This approach can contribute meaningfully to peace education in the digital age by continuously refining the balance between historical accuracy, ethical representation, and immersive interactivity.

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