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Journal of Education and Learning Environments

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ARTICLE

Augmented Enactive Learning:Fostering Environmental Awareness through AR Immersive Theater

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ABSTRACT

In this article, we examine the potential of Augmented Reality (AR)-enhanced immersive theatre as an approach for enactive learning and as a tool for raising awareness of environmental crises. Grounded in the theories of embodied cognition and immersion, the analysis focuses on how active participation in such environments can strengthen learners' engagement and foster a deeper understanding and retention of environmental themes. To investigate this potential, two groups of school students attended the performance: *La Germination, D'autres mondes possibles* (by Joris Mathieu and Nicolas Boudier, "Compagnie Haut et Court") at "Les Ateliers – Théâtre Nouvelle Génération" (Lyon, France) in November 2023. After the performance, participants completed a post-performance questionnaire designed to assess the impact of the augmented reality technology, using AR glasses on their experience and understanding. Preliminary findings based on their responses indicate that participants reported an embodied and emotional connection to environmental issues, suggesting that augmented immersive theatre can facilitate transformative learning experiences.

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ARTICLE INFO

Received: 12 March 2025 | Revised: 20 April 2025 | Accepted: 29 April 2025 | Published Online: 16 May 2025

DOI: <https://doi.org/10.55121/jele.v1i1.729>

CITATION

Privas-Bréauté, V., 2025. Augmented Enactive Learning: Fostering Environmental Awareness through AR Immersive Theater. *Journal of Education and Learning Environments*. 1(1): 30–53. DOI: <https://doi.org/10.55121/jele.v1i1.729>

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It is argued, in this study, that this new form of theatre represents a promising environment for innovative, augmented enactive learning methodologies but that further research is needed to evaluate its long-term educational impact.

Keywords: Augmented Immersive Theater; Embodied Cognition; Enactive Learning; Environmental Awareness; Transformative Learning

1. Introduction

Since the beginning of the 21st century, Immersive Virtual Environments (IVEs) and synthetic worlds have been explored as particularly innovative pedagogical tools for language learning^[1–5]. Platforms such as *Second Life* have stood out for their ability to offer dynamic, interactive environments in which learners can play a variety of roles, participate in meaningful social interactions, and explore intercultural dimensions, including discovering foreign practices, customs, and traditions or visiting virtual reproductions of iconic places. The use of these spaces, backed by constructivist^[6] and sociocultural^[7] theories, offers learners the opportunity to engage in simulated scenarios that recreate communicative situations close to reality^[8], where they become co-constructors of knowledge through problem-solving, interaction, and critical reflection^[9]. These technologies have, therefore, been associated with active learning approaches^[10–12], which prioritize learner participation, collaboration and engagement. The immersive nature of virtual worlds captures their attention, which, according to Van Lier's perception-in-action principle^[13], fosters active participation and sustained engagement on their part. Moreover, embodied cognition theories^[14,15] provide a broader understanding of how learning emerges through the dynamic interplay between body, mind, and environment. Varela, Thompson and Rosch's enactive approach^[16,17], for instance, posits that knowledge is actively constructed through sensorimotor engagement with the world. In immersive contexts, learners are participants whose perceptions and actions continuously shape their understanding. Such an embodied enactive perspective highlights the central role of bodily involvement, spatial awareness and multi-sensory integration in fostering deep learning experiences. To complement this view, research in affective neuroscience, particularly the works of Panksepp^[18], Damasio^[19] and Immordino-Yang^[20,21], underscores the interdependence of emotion, cognition, and decision-making in learning. They have shown

that emotional engagement influences attention, memory consolidation and meaning-making processes, all of which are determinant in immersive environments. When learners' bodily sensations, emotional responses and cognitive processes are simultaneously activated, the experience becomes more memorable and transformative^[22–24]. These findings provide a strong theoretical basis for exploring how immersive environments can enhance both engagement and retention in educational contexts.

While these findings highlight the theoretical potential of immersion, the development of extended reality (XR) tools (encompassing virtual reality, augmented reality and mixed reality) has translated this potential into practice and amplified learners' emotions and sensations tenfold. Several types and degrees of immersion can be distinguished^[25–27] and, more specifically, an interoceptive immersion^[28], where learners live the experience in the first person, as if they were there^[29,30], and an exteroceptive immersion^[31,32]. These two approaches complement each other: the former can promote total engagement and a state of "flow"^[33], while the latter may enable learners to step back and reflect on their experience, and, in educational contexts, their learning. This link between sensory immersion and reflective distancing may represent a major asset for the long-term consolidation of learning by mobilizing both language skills and the learners' ability to reflect on their own experiences. The integration of immersive and interactive environments pushes active pedagogical models further and offers new opportunities for embodiment, emotional engagement and situated cognition^[34,35]. This evolution is encapsulated in the concept of Augmented Active Learning (AAL)^[36–38], which builds upon the foundations of active learning by leveraging the potential of immersive technologies. AAL enhances traditional approaches by introducing multisensory, interactive and context-rich experiences that deepen cognitive involvement in the learning process. In the field of language learning, for example, AAL enables learners to experience language in authentic, meaningful

and engaging contexts, which develop not only linguistic competences but also intercultural awareness^[39,40]. In this sense, AAL positions the learner as an active agent navigating dynamic environments. However, while AAL integrates multi-sensory technologies to enhance engagement and interactivity, we argue that it does not fully capture the fundamentally embodied, situated nature of learning in immersive environments or develop emotional resonance^[41]. In this study, we propose shifting from Augmented Active Learning (AAL) to Augmented Enactive Learning (AEL). Rooted in enactive theories of cognition, AEL views learning as an emergent process enacted through the dynamic interplay between perception, action and emotion within context-rich environments. This shift is particularly relevant for immersive theatre experiences, where technological augmentation intertwines with narrative, spatial and affective dimensions to produce learning processes that are at once cognitive, emotional and sensorimotor.

In recent years, the performing arts have indeed integrated new technologies to expand the boundaries of audience engagement and storytelling^[42–44]. From Virtual Reality (VR) and Augmented Reality (AR) to motion capture and interactive scenography, these innovations have reshaped the relationship between performers and spectators, creating hybrid spaces where physical and digital realities intertwine. This technological shift not only enhances sensory immersion^[45] but also opens new opportunities for experiential learning, allowing audiences to engage with complex themes through embodied and participatory experiences. International initiatives illustrate the growing role of augmented immersive theatre in learning environments, and recent studies demonstrate that AR-based theatrical scenarios can significantly increase students' motivation and engagement in skills development^[46,47]. In Australia, for instance, the experimental production “Alex” integrates AR technology in theatre as a narrative therapy addressing body image and self-esteem, highlighting the potential of immersive theatre for emotional and clinical interventions. In the UK, the National Theatre’s Immersive Storytelling Studio and AR smart caption glasses exemplify efforts to enhance engagement and accessibility through live AR/VR techniques. In Europe, Mixed Reality Heritage Performances (MRHP) have paired AR glasses with live theatre to engage audiences in critically confronting colonial

narratives in heritage. More specifically, in Greece, the VOXReality collaboration is piloting AR-captioned theatre, providing live subtitles and contextual commentary to foster inclusivity and cross-cultural understanding during performances. Such contexts encourage critical reflection and support AEL, where knowledge emerges through embodied participation as learners co-construct meaning via physical, emotional and imaginative engagement with multi-sensory stimuli. By adopting this perspective, we aim to investigate how augmented immersive theatre — considered a new hybrid genre that bridges theatre and emerging XR technologies and uses digital augmentation to reinforce and expand the immersive potential of performance — can foster deeper forms of understanding and ecological awareness that extend beyond traditional models of active learning.

This study focuses on *La Germination, D’autres mondes possibles*, an AR-enhanced immersive performance by Joris Mathieu and Nicolas Boudier (Compagnie Haut et Court), presented at “Les Ateliers – Théâtre Nouvelle Génération” (Lyon, France) in 2023. The piece stages a speculative exploration of environmental collapse and invites participants to inhabit an augmented scenographic environment where technological enhancement amplifies sensory immersion. By blending live performance with digital augmentation, the production creates a deeply affective space that encourages audiences to confront ecological crises while envisioning alternative futures for humanity. Within this context, this article addresses two main research questions:

1. How can augmented immersive theatre function as a novel enactive learning environment where embodied participation fosters deeper engagement, understanding, and retention of environmental themes?
2. To what extent can these immersive experiences stimulate audience reflection on humanity’s potential futures, particularly in relation to ecological collapse and transformation?

To address these research questions, a protocol was implemented, relying on a post-performance questionnaire administered to audiences including school groups who attended *La Germination*. The questionnaire, originally designed for non-scientific purposes, aimed to capture how

spectators experienced the play with AR glasses and how they emotionally and cognitively engaged with its themes. Using a mixed-methods approach, this study analyzes audience responses through the lens of embodied cognition theories to determine how immersive and technological augmentation strategies contribute to the embodiment of knowledge and, potentially, to a transformation in participants' awareness of the future of humanity. Preliminary findings derived from the post-performance questionnaire suggest that audience members reported a heightened sense of connection with environmental themes after the performance, which highlights the potential of augmented immersive theatre as a promising environment for augmented enactive learning. However, further research is required to evaluate its long-term impact on awareness and knowledge retention.

2. Materials and Methods

The research was conducted in the context of two performances of the augmented immersive play *La Germination, D'autres mondes possibles* presented for secondary school students and their teachers at "Les Ateliers – Théâtre Nouvelle Génération" (TNG) in Lyon (France) in 2023. First, the play itself is described to emphasize its artistic design and technological augmentation (i.e., AR glasses) and then the questionnaire used to capture audience experiences is presented. Together, these materials provide the empirical basis for investigating how immersive theatrical experiences can support embodied learning, engagement and awareness of environmental issues, in line with the theoretical framework of embodied and enactive cognition.

2.1. Context of the Study and Participants

In November 2023, TNG incorporated *La Germination, D'autres mondes possibles*, an innovative theatrical work, into its program for the "Micro Mondes" festival. This is a biennial event celebrating immersive arts and contemporary creation through engaging experiences for audiences of performing arts and multimedia. The festival stands out for its innovative approach, inviting spectators to enjoy new artistic experiences. It provides a journey to discover artists from diverse backgrounds: theater, visual

arts, digital, music, and more. This festival is designed to be accessible to all audiences through experiences that are both poetic and unusual and immerse participants in intimate, sensory worlds.

One of the major objectives of the "Micro Mondes" festival is to place the public at the heart of the narrative of the works presented. Indeed, the integration of interactive and immersive elements into the festival's design aims to question and transform the way we apprehend art and culture. It encourages spectators to reflect on their behavior and consider new perspectives. This approach establishes an intimate relationship between artistic creations and the audience and transforms each participant into a potential actor in the narrative.

La Germination, D'autres mondes possibles was conceived by Joris Mathieu and Nicolas Boudier, in collaboration with the theatre company "Haut et Court". It has a hybrid quality because it integrates elements of traditional theater and augmented reality. It aims to explore contemporary utopias and reflections on the prospects for a more desirable future and revolves around a central question: "What path should we choose to make a more desirable world possible?" This question is staged through an immersive device where spectators, equipped with AR glasses, are plunged into an interactive environment for 70 minutes. The play aims to stimulate critical reflection on current social and environmental challenges through a sensory experience. Moreover, the use of AR in *La Germination* creates a universe where the boundaries between the real and the virtual are blurred. Viewers are invited to explore ideas and concepts invisible to the naked eye but perceptible thanks to technology. This approach aims to stimulate the collective imagination and encourage reflection on emerging utopias and their potential impact on the future of society. This immersive experience is designed to be both engaging and intellectually stimulating and should encourage discussion of contemporary issues.

Contrary to fully interactive or ambulatory immersive experiences, the participation of spectators remains deliberately minimal, contained, and aligned more with a reflexive form of engagement than with physical interaction or spatial exploration. Audience members are seated throughout the performance, and their participation is solicited primarily through simple non-verbal gestures,

such as raising or lowering their thumbs in response to questions posed by the performers. These gestures, though modest, serve a dual function. On the one hand, they allow each spectator to position themselves ethically or emotionally in relation to the issues being raised, often tied to ecological, existential, or societal choices. On the other hand, this form of collective signaling creates a shared atmosphere of introspection, subtly revealing the diversity of responses within the group without forcing verbalization or confrontation. Importantly, there is no direct interaction between audience members and performers. The performance maintains a clear distinction between those on stage and those in the audience, yet this boundary is softened by the invitation to reflect, judge and, respond, albeit silently. This form of participation, while limited in its physical expression, engages spectators cognitively and affectively and prompts them to situate themselves within the themes of the piece, particularly those related to environmental responsibility and the imagination of alternative futures.

The play features several characters, each voicing a distinct vision of the world. For example, a character advocates total respect for all living things, while another defends a world without borders, where wealth is equitably distributed. These interactions explore different perspectives and encourage the audience to consider innovative solutions to current problems. This diversity of viewpoints enriches the debate and should enable viewers to reflect on their own convictions and values. Therefore, the play aims to provoke in-depth reflection on the individual and collective choices that shape our future. By integrating the public into the creative process, it makes art accessible and engaging, and is in line with a desire to promote critical thinking and civic engagement through art. In this respect, *La Germination, D'autres mondes possibles* represents an effort to blend art and technology to explore contemporary utopias and engages the public in the active construction of novel worldviews, thereby contributing to collective reflection on the challenges and aspirations of contemporary society.

To investigate how audiences experienced this augmented immersive environment, TNG members distributed a questionnaire to 120 spectators, which corresponds to 2 groups of 50 secondary school students and 10 adults accompanying them. They collected 75 responses. Findings

related to these participants are presented in detail in the Results section below.

2.2. Data Collection Tools

This study uses the questionnaire (**Appendix A**) used to capture audience experiences. Developed by Anaïs Bourgeois, the production administrator of the TNG and her team, the questionnaire includes several scales measuring engagement, environmental awareness, and emotional response. These scales are designed to explore how participants interact with the performance and its augmented reality components. As the questionnaire was originally aimed for non-scientific purposes, no formal reliability assessment was conducted, and the results presented in this article are interpreted exploratorily. Indeed, the questionnaire was designed as a post-performance evaluation tool for this AR theatre production. Its primary purpose was to collect feedback from spectators regarding their experience of using AR glasses during the performance to assess both the technical aspects of the device and the aesthetic, emotional, and perceptual dimensions of the augmented experience. It consists of fifteen main questions, some of which include sub-questions, resulting in a total of approximately twenty-five distinct items. The form is designed to take no more than five minutes to complete.

The first section of the questionnaire (from Question 1 to Question 3a) gathers basic demographic data through a single multiple-choice item asking respondents to select their age range from five predefined categories. This is followed by a set of questions assessing previous exposure to immersive technologies. Specifically, respondents are asked whether they have ever used a VR or AR headset. For each of these technologies, those who answer affirmatively are invited to indicate the context in which the device was used, such as during a performance, an exhibition or another activity like gaming. These questions serve to contextualize the respondents' level of familiarity with the medium, which may affect their reception of the AR performance.

Subsequent items (Question 4) explore the participants' general cultural practices. This question enquires about the frequency with which they attend dance or theatre performances and uses a five-point scale ranging from "very often" to "never." This provides insight into their

habitual engagement with live performance, potentially influencing how novel or familiar the augmented format felt.

A central portion of the questionnaire focuses on the AR glasses themselves and examines their physical comfort, usability, and the continuity of use during the performance. One item (Question 5) asks participants to evaluate the comfort level of the glasses on a five-point scale, while another (Question 6) asks whether they kept the glasses on throughout the performance, removed them occasionally, or took them off entirely. An open-ended sub-question (Question 6a) invites participants to explain their reasons if they did not wear the device continuously.

The technical reliability of the AR system is explored in a series of questions (Questions 7 to 7c) that ask whether participants encountered problems visualizing the virtual content. If so, they are asked to evaluate whether re-scanning visual cues (e.g., posters or markers, as had to be done to connect the AR glasses before the play began) resolved the issue. A follow-up prompt encourages them to describe the problem in their own words. An additional question explores the actions taken when technical problems could not be resolved, such as removing the device after one or several attempts.

The questionnaire also addresses physiological effects, particularly visual fatigue (Question 8). Participants are asked whether they experienced eye strain, and if so, to what degree. Two further questions relate to visual health: respondents indicate whether they wear prescription glasses (Question 9), and if so, they specify the type of visual impairment corrected (e.g., myopia, astigmatism, hypermetropia, or presbyopia). This information helps identify possible correlations between visual correction and the perceived comfort or effectiveness of the AR device.

The questionnaire then turns to issues of spectatorship and perceptual novelty (Questions 10 to 12). Participants are asked whether the ability to see both the live stage and virtual images simultaneously through the semi-transparent glasses seemed new to them. They are also invited to indicate the extent to which this AR experience either enhanced or disrupted their sense of immersion in the performance. Another question explores the degree of attention paid to other audience members during the show, an indirect indicator of co-presence and shared experience in a technologically mediated context.

Emotional responses to the augmented experience are addressed in Question 13, which asks participants whether the AR format generated a sense of frustration — such as viewing the performance through a technological filter — or conversely, a sense of aesthetic or perceptual satisfaction. Artistic reception is examined through two closed questions (Questions 14 and 15) that ask whether any visual or staging effect stood out positively or negatively. In both cases, respondents are invited to elaborate on their impressions through open-ended sub-questions.

The final item of the questionnaire (Question 16) offers an open comment box, allowing participants to share additional observations, insights or feedback that were not addressed in the structured questions. This space encourages more personal or unexpected responses and adds depth to the overall dataset.

This questionnaire combines multiple-choice, scaled, and open-ended questions to provide a comprehensive evaluation of the spectator's experience. It assesses familiarity with immersive technologies, technical performance of the AR device, physical and visual comfort, emotional and perceptual engagement, and the overall impact of the augmented performance format on spectatorship. By capturing both objective and subjective dimensions, it contributes insights into the affordances and limitations of AR as a medium for live performance.

2.3. Research Design

In this study, we follow a mixed methods design, integrating both quantitative and qualitative analyses. Quantitative data were derived from participants' responses to closed-ended items in the questionnaire, while qualitative data came from open-ended responses reflecting their sensory, emotional, and cognitive experiences. All the responses of the participants were organized into an Excel spreadsheet to ensure that the data are easily analyzable, accessible, and support TNG members' goal of evaluating the impact of the immersive theater experience on participants' perception of environmental issues and retention of themes. The data were analyzed using descriptive statistics and thematic coding, following an approach similar to that employed in MAXQDA for mixed methods research.

3. Results

This section presents the main findings of the study, focusing on six key dimensions: participants' prior experience with AR glasses across age groups, the relationship between embodied participation and immersion associated with continuous AR glasses wearing, the impact of technological augmentation on perceptual and cognitive engagement, the understanding of environmental themes conveyed through the performance, the relationship between previous experience of AR/VR and immersion and the balance between familiarity and technological novelty in augmented immersive theatre. In this analysis, the focus

will be on a select number of responses that align with the central inquiries addressed in this paper.

3.1. Age of the Respondents and Their Familiarity with AR

Figure 1 presents the proportion of respondents categorized by age, with the categories ranging from under 18 to over 65 years of age. Each segment represents a percentage of the total sample and illustrates the demographic diversity of the study population. Although the sample size is relatively small ($N = 75$), percentages are provided to facilitate comparison between categories and to improve readability.

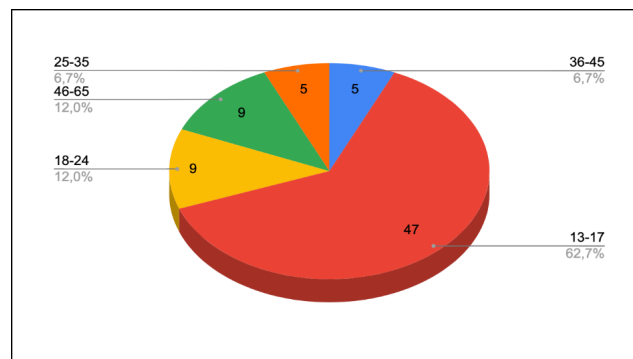


Figure 1. Age Distribution of the Respondents.

This distribution shows that most of the people who answered the questionnaires were school-age children, which is why there were more younger respondents. This should be considered when interpreting the results, as it may influence certain findings related to generational trends and age-related preferences.

To further contextualize these respondents, **Table 1** presents their prior experience with AR glasses across different age groups. It provides a breakdown of responses into three categories: “Yes”, “No”, and “I don’t know”, which allows for an overview of the familiarity with AR technology among different generations.

Table 1. Participants' prior Experience with AR Glasses.

3- Have You Previously Had the Opportunity to Use Augmented Reality Glasses?				
1-Age group	I don't know	No	Yes	Total
13-17		30 (40%)	17 (22.7%)	47 (62.7%)
18-24		9 (12%)		9 (12%)
25-35		3 (4%)	2 (2.7%)	5 (6.7%)
36-45	1 (1.3%)	3 (4%)	1 (1.3%)	5 (4.6%)
46-65		6 (8%)	3 (4%)	9 (12%)
Total	1 (1.3%)	51 (68%)	23 (30.7%)	75 (100%)

As shown, most participants reported no prior experience with AR glasses, while only 23 out of 75 had used them before. This lack of familiarity was especial-

ly pronounced among younger participants aged 13-17 (30 had never used AR glasses), who also represented the largest share of respondents. Furthermore, a small number

of older participants (25–35 and 46–65 groups) reported slightly higher exposure rates, although overall, previous experience with AR technology was limited across all age groups.

3.2. Embodied Participation and Immersion linked to Continuous AR Glasses Wearing

The experience of embodied participation in the play was closely tied to the continuous wearing of AR glasses throughout the performance. While spectators remained seated and their physical interaction was limited to simple

gestures, the act of wearing the AR headset created a constant physical interface between body and environment. This prolonged wearing of the device shaped not only the perceptual experience but also the degree of immersive presence and the awareness of one's own body as part of the scenographic apparatus. For some participants, the headset acted as a perceptual filter, enhancing visual immersion and symbolic integration into the fictional world. For others, however, it highlighted the technological mediation, prompting concerns about comfort, distraction, and physical constraints (**Figure 2**).

5- Would you say that wearing the Augmented Reality glasses was rather comfortable or uncomfortable?

● Not comfortable but not uncomfortable ● Quite uncomfortable
● Somewhat uncomfortable ● Very uncomfortable

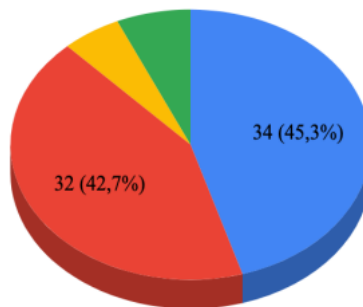


Figure 2. Comfort felt while wearing AR Glasses.

As **Figure 2** suggests, despite a few comments about the weight or discomfort of the AR glasses, many rated them as “not comfortable but not uncomfortable” (45.3%) or “quite uncomfortable” (42.7%). So, the general usage

patterns indicate a broad acceptance of the device by the audience. As a matter of fact, most spectators kept their AR glasses on for the entire duration or took them off only briefly, as seen in **Figure 3**.

6- Did you keep the glasses on during the entire performance?

● Yes
● No
● I occasionally lifted them

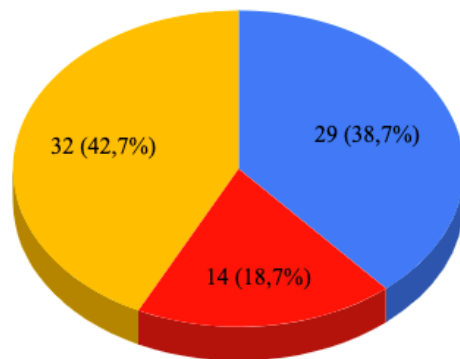


Figure 3. Keeping AR Glasses on during the entire Performance.

These results suggest a level of tolerance to the device essential for continuous body immersion, with only 14 respondents completely removing the AR glasses during the performance. An analysis of the participants' responses

to the question, "If you haven't kept the device on or lifted it occasionally, can you explain why?" unveils the main reasons why participants chose not to keep their AR glasses on for the entire performance (**Table 2**).

Table 2. Reasons for not keeping AR Glasses throughout the whole Experience.

Category	Number of Responses	Percentage
Eye-related issues (pain, tiredness, irritation)	19	47.5%
Physical discomfort related to the device	17	42.5%
Headaches and migraines	12	30%
Desire to reconnect with reality / Curiosity	5	12.5%
Vision and visual quality problems	4	10%
General environmental discomfort (heat, bother)	4	10%
Technical malfunctions (headphones)	1	2.5%

The most reported issues were eye-related problems such as fatigue, irritation, and eye pain (47.5% of respondents). Physical discomfort caused by the device itself, such as pressure on the nose, forehead or a general feeling of heat, was cited by 42.5% of respondents. Headaches and migraines were also a significant concern, affecting 30% of respondents. Smaller proportions reported a desire to reconnect with reality or simple curiosity (12.5%), problems with visual quality (10%), and general environmental discomfort such as heat and the feeling of being disturbed (10%). Finally, problems related to technical malfunctions were cited by 2.5%. These results highlight the importance of ergonomics, visual comfort, and sensory balance when

designing or using immersive technologies for long periods of time (n.b. the show lasted 70 minutes).

3.3. Augmented Perception and Cognitive Engagement

To better understand how AR influenced spectators' perceptual and cognitive engagement, participants were asked to reflect on the quality of their experience in terms of emotional resonance and sensory enhancement. **Figure 4** presents the results of the question that asked participants whether AR performance made them feel frustrated (as though watching the show through a filter) or satisfied (as though experiencing an enhanced universe).

13- Did this mode of augmented reality performance cause you frustration (by watching the show through a filter), or cause you satisfaction (by providing an enhanced universe)?

● No frustration, no satisfaction ● High satisfaction ● A great deal of frustration ● Slight frustration
● Slight satisfaction

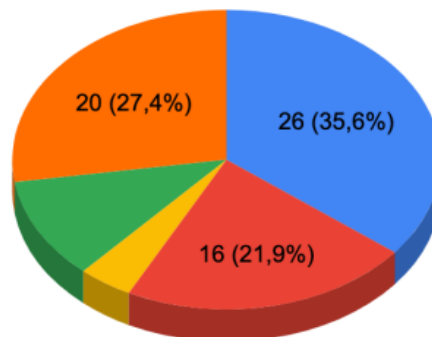


Figure 4. Frustration to see through a Filter.

Audience responses were distributed across four main groups: 35.6% reported a neutral experience, 27.4% expressed slight satisfaction, 21.9% reported a positive perception of the AR-enhanced environment, while 11% experienced slight frustration and 4.1% reported a high level of frustration.

Beyond individual perception, the experience also unfolds within a shared space, where spectators' attention is not only directed towards the augmented performance but also shaped by their co-presence with others. This dynamic raises the question of how collective presence influences individual focus and whether attention can be distributed without diminishing immersion. Although some were watching other viewers, this didn't distract them from paying attention to the show (Figure 5).

The results show that while most spectators reported paying attention to other audience members sometimes (50%), only a small portion did so often (14.9%) or very often (1.3%). Conversely, a significant number reported doing so once (21.6%) or never (12.2%). This suggests that, while interactions with other audience members were limited, participants remained attentive to the staging and visual effects (Figure 6).

When asked if they noticed any staging or visual effects, many respondents (70.8%) indeed answered positively. The respondents who identified a striking scenic or visual effect often related it to moving virtual animals or environmental symbols (lights, textures, metamorphoses of the ground). Table 3 categorizes their responses according to recurring visual and staging motifs.

12- During the performance, did you often pay attention to the behavior of other audience members?

● Once ● Often ● Sometimes ● Very often ● Never

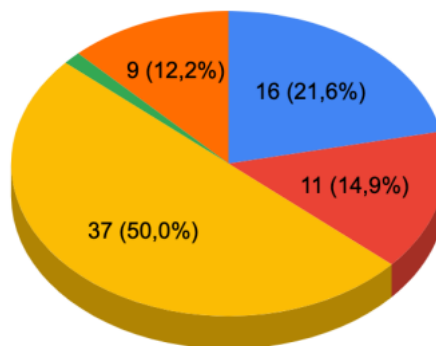


Figure 5. Paying Attention to other Audience Members' Behaviors.

14- Was there a particular staging or visual effect in the performance that you especially liked or found striking?

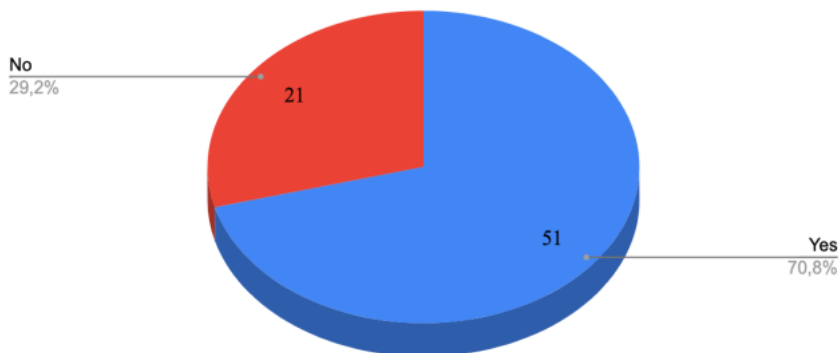


Figure 6. Striking Effects.

Table 3. Categories of Responses about Striking Effects.

Category	Examples from responses	Number of mentions	Percentage
Animals (stingray, whale, butterflies, etc.)	“The ray at the beginning”, “butterflies”, “the whale”, “the aquatic animal”, “animals coming towards us”	15	30%
Augmented Reality / Depth / Immersive effects	“Change dimensions thanks to augmented reality”, “widening the field of vision”, “field made of particles”	7	14%
White Lines / Squiggles / Particles	“White squiggles”, “white lines that fade”, “dots invading the stage”, “spatial line”, “particles”	7	14%
Stage Animation / 3D graphics / Vector people	“Animated sets”, “moving 3D graphics”, “large people in vector graphics”, “graphics fill the room”	6	12%
Lighting Effects	“Sodium light”, “the lights at the end”, “luminous circles”, “highlighting actors against yellow background”	5	10%
Nature / Greenery / Plants	“Green plants growing”, “greenery”, “plants around cans”, “The earth unravelling in luminous circles”, “the earth that decomposes and melts”	5	10%
Transhumanism / Virtual characters	“Virtual version of actors”, “transhumanist speech”	2	4%
People / Characters in blue	“People in blue”, “blue characters”	2	4%

Some of these elements are directly connected to the show’s environmental themes and highlight its exploration of the interplay between nature, technology, and human presence. Only 50 responses out of 75 have been completed. It should be noted that some responses include multiple elements and were therefore counted in more than one category. This categorization reveals that animal imagery and movement were the most striking features for the audience (30%), followed by immersive spatial transformations and augmented depth (14%). The recurrence of abstract visual effects (lines, particles) and animated visuals also reflects the centrality of digital scenography in shaping engagement.

3.4. Immediate Retention of Environmental Themes

Participants’ immediate retention of environmental themes was assessed by examining the elements they recalled and interpreted, with references to visual effects depicting the earth, decomposition or transhumanism, indicating an active cognitive engagement with the performance. **Table 4** is a classification of the answers from question 14a that are explicitly or implicitly linked to environmental issues, based on references to nature, ecological transformation, or environmental symbolism in the staging.

Table 4. Classification of the Responses linked to Environmental Issues.

Response	Environmental Link
“The earth unravelling in luminous circles”, “the green plants growing”	Symbolic of life cycles, regeneration, and ecological balance
“Earth that decomposes and melts”	Evokes decay, climate change, or environmental degradation
“The ‘robotic’ whale crossing the greenhouse”	Hybrid of nature and technology; references to endangered marine life
“Rays”, “whales” and “butterflies”	Emblematic of biodiversity and fragile ecosystems
“The stingray”, “the spaceship”, “the little green drone”	Contrasts between natural and artificial life forms
“The planets”, “the virtual characters around the cans”, “the plants”	References to planetary ecology and human waste
“Greenery”	Direct reference to plant life and environmental aesthetics
“The aquatic animal at the very beginning”	Marine imagery linked to ecosystem awareness
“When the animals (stingray, butterflies) come towards us”, “the confetti at the end”	Animal presence suggesting immersive connection with nature
“At first, the animal passing over us”	Dramatic staging of nature confronting the viewer
“Butterflies”	Symbol of transformation and biodiversity
“The end effect, where the environment is made up of particles”	Visual metaphor for ecological disintegration or reformation

While **Table 4** focuses on how spectators retained and interpreted environmental themes through symbolic or narrative elements, **Table 5** shifts the perspective towards the medium itself. It explores how the technological dimension of the augmented performance (rather than its

thematic content) was received and remembered by the audience, which offers insight into the relationship between form and message retention. It is based on 68 total responses (questions 14a and 16) and excludes empty “no” answers (counted separately).

Table 5. Participants’ Feedback on AR Experience.

Category	Description	Sample Responses	% of Responses
Discomfort / Technical limitations	Physical discomfort, overheating, issues with glasses/helmet or gesture interactivity	“Glasses felt heavy”, “Slight overheating”, “Helmet not suitable for curly hair”, “Gestures didn’t work”	38% (18)
Praise for innovation & interactivity	Overall enthusiasm, mentions of interactivity, audio or multi-sensory aspects	“I loved the show”, “Interactive”, “Voices and sounds were pleasant”, “Graphics and light could be improved”	30% (14)
Mixed response to technology	Appreciation of innovation but with caveats about mediation, screen effect or early-stage development	“Technology is promising but feels like it’s being used for the first time”, “Having a screen removed the wow effect”	21% (10)
Immersive impact / Emotional response	Positive personal or emotional engagement, reflective or lasting effect	“Show I’ll remember for the rest of my life”, “It gave me a lot to think about”, “Joined an association afterwards”	17% (8)
Suggestions for improvement	Constructive feedback on visual, auditory or experiential aspects	“Graphics could be better managed”, “Why not use sound more?”	15% (7)
Visual overload / Attention conflict	Visual effects overshadowing narrative or actors	“Visuals were so strong we concentrated more on them than the actors”, “Scribbles at the end distracting”	13% (6)
Frustration with spectator experience	Issues with accessibility or audience behavior	“Shame for spectacle wearers”, “Too many people falling asleep”, “Room lit up the whole time”	11% (5)
No specific feedback / Neutral	Responses like “No”, “Not particularly” or blank entries	“No”, “Not especially”, “No thank you”	30 entries

Participants’ feedback on the AR component of the performance revealed a range of responses, with some reporting immersion and engagement, while others highlighted discomfort or distraction caused by the headset. The most frequently reported category was discomfort and technical limitations (38%, $n = 18$), which included issues such as physical discomfort, overheating, and difficulties with AR glasses, helmets, or gesture-based interactivity. Praise for innovation and interactivity was also common (30%, $n = 14$), with participants highlighting the interactive and multi-sensory aspects of the performance. Other responses included mixed reactions to technology (21%, $n = 10$), immersive impact and emotional engagement (17%, $n = 8$), suggestions for improvement regarding visual and auditory aspects (15%, $n = 7$), visual overload or attention conflict (13%, $n = 6$), and frustration with the spectator experience (11%, $n = 5$). Finally, a few participants provid-

ed neutral or no specific feedback. Overall, the responses indicate a diversity of experiences with the AR elements, ranging from technical challenges to enthusiastic appreciation of the immersive and interactive features.

3.5. Previous Experience and Immersion

To better understand how previous experience with immersive technologies might shape the audience’s perception and comfort, we examined whether prior use of AR glasses influenced how immersive the performance felt for viewers. Specifically, we compared participants’ comfort levels with the AR headset based on whether they had already used such devices in the past. **Table 6** presents the distribution of responses to the question about prior experience with AR glasses (Question 3) alongside their reported comfort levels while wearing the headset (Question 5).

Table 6. Previous Experience and Immersion.

5- Would You Say that Wearing the Augmented Reality Glasses Was Rather Comfortable Or Uncomfortable?					
3- Have you previously had the opportunity to use augmented reality glasses?	Not comfortable but not uncomfortable	Quite uncomfortable	Somewhat uncomfortable	Very uncomfortable	Total
I don't know	1 (1.3%)				1 (1.3%)
No	23 (30.7%)	25 (33.3%)	1 (1.3%)	2 (2.7%)	51 (68%)
Yes	10 (13.3%)	7 (9.3%)	3 (4%)	3 (4%)	23 (30.7%)
Total	34 (45.3%)	32 (42.6%)	4 (5.3%)	5 (6.7%)	75 (100%)

Interestingly, among those with no prior experience with AR, a significant portion (25) found the glasses “quite uncomfortable”, and 23 rated them as “not comfortable but not uncomfortable”. Only a small number (3 in total) described them as “somewhat” or “very uncomfortable”, suggesting that unfamiliarity did not systematically lead to strong discomfort but rather to a general ambivalence or mild unease. Conversely, those who had already used AR glasses reported slightly more polarized responses. While 10 described their experience as “not comfortable but not uncomfortable”, and 7 as “quite uncomfortable”, a smaller share (6 out of 23) reported levels of discomfort ranging from “somewhat” to “very uncomfortable”. Overall, the results reveal that although a large majority of the audience had no prior experience with AR, discomfort was not overwhelmingly negative but rather moderate. The glasses

were perceived as tolerable by most, albeit not fully integrated or forgotten during the experience.

3.6. Comfort and Novelty in New Technology

Another important aspect of the experience relates to the relationship between physical comfort and the sense of novelty sparked by the technology. We explored whether participants who felt physically at ease while wearing the AR glasses were more likely to perceive the augmented reality overlay as innovative (and therefore, engaging). In other words, we wondered whether comfort enhances openness to technological novelty. **Table 7** cross-analyzes responses to the question assessing the perceived novelty of viewing virtual images overlaid on the stage and performers (Question 10) with those evaluating the comfort of wearing the AR glasses (Question 5).

Table 7. Comfort and Novelty in new Technology.

10- Did the Ability to See the Stage and Performers Directly through the Transparent Lenses While Also Seeing Virtual Images Seem New to You?						
5- Would you say that wearing the augmented reality glasses was rather comfortable or uncomfortable?	(no answer)	No, not at all	No, not really	Yes, a little	Yes, absolutely	Total
Not comfortable but not uncomfortable			4 (5.3%)	12 (16%)	18 (24%)	34 (45.3%)
Quite uncomfortable	1 (1.3%)	2 (2.7%)	5 (6.7%)	8 (10.7%)	16 (21.3%)	32 (42.6%)
Somewhat uncomfortable				3 (4%)	1 (1.3%)	4 (5.3%)
Very uncomfortable			1 (1.3%)	2 (2.7%)	2 (2.7%)	5 (6.7%)
Total	1 (1.3%)	2 (2.7%)	10 (13.3%)	25 (33.4%)	37 (49.3%)	75 (100%)

The responses reveal a clear overall sense of novelty: 25 respondents selected “Yes, a little” and 37 responded “Yes, absolutely”, accounting for 82.7% of the sample (62 out of 75). This strongly suggests that the layered visual experience offered by the AR system was

unfamiliar to most viewers. Only 12 participants felt that this was not new, with just 2 choosing “No, not at all”. When cross-referenced with reported comfort, an interesting pattern emerges. Among those who found the glasses “not comfortable but not uncomfortable”, the majority

still indicated that the experience felt new (30 out of 34). A similar trend is seen among those who found the glasses “quite uncomfortable”: 24 out of 32 nonetheless described the experience as novel. Even among the very small group who felt the glasses were “very uncomfortable”, four out of five still acknowledged the novelty of the perceptual layer, including two who selected “Yes, absolutely”. So, in response to the question, “*Does comfort enhance openness to technological novelty?*”, the data suggest that comfort is not necessarily a prerequisite for perceiving novelty. In fact, the sense of novelty appears to operate independently of physical ease, at least in this context. Most participants, regardless of discomfort, remained cognitively open and perceptually responsive to the unfamiliar dimension introduced by the AR system.

4. Discussion

The following discussion interprets the findings from the post-performance questionnaires, highlighting the complex and multifaceted experience of participants. It begins by examining the eco-embodied spectator and explores how sensory engagement can foster knowledge and awareness of environmental issues. It then considers patterns of engagement and emotional response, alongside participants’ perceptions of comfort, novelty, and technological mediation. Our discussion proceeds to analyze participants’ immediate engagement with environmental themes, as well as the potential for the performance to foster transformative cognitive, emotional, and embodied experiences. Finally, it addresses the pedagogical implications arising from these findings, before presenting a critical reflection on the study’s limitations and recommendations.

4.1. The Eco-Embodied Spectator

The notion of the eco-embodied spectator captures how participants’ bodily and sensory engagement with the augmented immersive performance shapes their understanding of environmental themes. Responses indicating active interpretation of visual effects related to the Earth, decomposition, or transhumanism (Tables 3 and 4) suggest that the immersive and interactive elements of *La Germination* enabled participants to process complex ecological content through embodied cognition. These findings align

with theories of enactive learning, in which knowledge is co-constructed through sensorimotor engagement and situated interaction. The AR component, by overlaying technological augmentation onto the live performance, provided a multi-sensory scaffold that appears to have facilitated meaning-making and reflection on environmental crises.

These findings on participant engagement can be further understood through the lens of the three sensory pathways of embodied immersion (interoception, exteroception, and proprioception) ^[48], which together shape the depth and quality of immersive experiences in AR-enhanced theatre.

4.1.1. Interoception and Internal Bodily Awareness

Several participants reported symptoms, such as headaches, eye fatigue, and overheating, which reflect interoceptive discomfort (Table 5). These responses point to an internal bodily awareness triggered by the equipment. Instead of contributing to immersion, such sensations disrupted presence by shifting attention inwards, making participants hyper-aware of bodily constraints rather than thematic immersion. We might deduce then that interoceptive discomfort potentially reduces affective receptivity and hinders the contemplative engagement necessary for ecological reflection. This aligns with Damasio’s somatic marker hypothesis ^[49], which suggests that strong negative bodily signals compete with cognitive engagement, potentially weakening memory encoding. In this case, the body becomes a site of friction, resisting rather than enhancing immersion.

4.1.2. Exteroception and Sensory Interaction with the Environment

AR devices, particularly head-mounted glasses, alter visual exteroception by overlaying digital elements onto the physical stage. Most responses from the questionnaire (Table 5) relate to exteroceptive immersion, with participants describing the intensity of visual stimuli, audio effects, and augmented scenography. Mentions of “scribbles,” “butterflies,” or “the whale in the greenhouse” reflect strong external sensory activation, which likely draws attention to natural or speculative ecosystems. The use of

natural imagery and environmental symbolism (animals, plants, spatial dissolutions) anchored the eco-conscious message in visceral experiences. For some, exteroceptive immersion heightened emotional and cognitive engagement, which likely reinforced ecological awareness. Yet for others, excessive visual stimulation may have weakened interpretive focus because the tension between mediated vision and natural perception can produce perceptual fatigue, especially for individuals unfamiliar with AR technology (**Table 7**). Indeed, some viewers noted that these sensory inputs overpowered narrative clarity, suggesting that if not well balanced, exteroceptive overload can divert attention from thematic content, including ecological messages.

4.1.3. Proprioception, Bodily Position and Movement

The weight, fit, and physical pressure of the AR headset (reported as “quite uncomfortable” by 42.5% of participants in **Figure 2** and explained in **Table 2**) affected proprioceptive awareness. Proprioceptive cues are less frequently mentioned (**Tables 3 and 5**), but a few responses allude to spatial awareness (“tempted to look around like in VR”, “field of vision widened”, “the animal passing over us”). These indicate moments where the spectator’s sense of spatial embodiment was engaged, often through augmented movement in the scene or the illusion of depth. Such feedback suggests that proprioceptive engagement, when successfully activated, can heighten presence and foster a sense of co-inhabiting a living ecosystem. This spatially grounded awareness likely might enhance empathetic identification with the environment represented on stage. Feeling physically enveloped by or co-present with other species or systems (e.g., animals flying overhead) may provoke greater ecological empathy, a key driver of environmental concern. However, in some cases, respondents became hyper-aware of the device, which reduced embodied flow and the seamless sensorimotor synchronization that immersive theatre aims to achieve. Interestingly, 14 participants voluntarily removed the glasses (**Figure 2**), expressing a desire to “reconnect with reality” or simply out of curiosity (**Table 2**). From an enactive perspective, these individuals engaged in meta-immersion^[50], alternating between being within the experience and

observing it from an external standpoint. This conscious shifting may have enhanced their critical awareness of technological mediation and influenced their interpretation of environmental themes.

Therefore, AR technology simultaneously engages all three sensory pathways but produces both enhanced immersion for some participants and sensory overload for others. These observations highlight that sustained embodied engagement depends on a delicate balance between technological mediation and bodily comfort, which emphasizes the importance of ergonomic design, perceptual coherence, and moderation in the intensity of AR augmentation.

4.2. Engagement and Emotional Response

Engagement and emotional response provide insight into how these embodied experiences translate into cognitive and affective involvement. Indeed, participants’ feedback reveals a spectrum of perceptual and emotional experiences, ranging from neutral or slight engagement to strong emotional responses, including lasting impressions and personal reflection (**Tables 2 and 5**). This variability underscores the subjective nature of immersive experiences and highlights the potential of augmented theatre to evoke both cognitive and affective involvement.

The combination of AR technology, interactivity, and multi-sensory cues contributed to participants’ engagement by mediating perception and action. Questionnaire responses show a mixed experience (**Figure 4**). The relatively high levels of satisfaction reported, combining “slight” and “high” satisfaction (49.3%), suggest that a substantial proportion of spectators successfully integrated virtual elements into their sensory-motor engagement with the performance space. This integration reflects both cognitive and emotional involvement, likely stimulated by the immersive and interactive features of the medium. When combined with responses in **Table 4**, these findings indicate that the immersive experience may favor an embodied, emotional understanding of ecological issues. Theories of augmented perception^[51,52] propose that such environments can expand the perceptual field, generate new affordances, and enhance both presence and immersion. **Table 3** further highlights the role of augmented perception in directing attention and shaping emotional responses, align-

ing with theories of enactive engagement and sensory-affective immersion.

Moreover, **Figure 5** illustrates a form of shared physical engagement rather than distraction: although some awareness of other spectators was reported, it did not significantly interfere with most viewers' experience. This relative lack of social distraction suggests that participants remained primarily focused on the performance itself, facilitating deeper engagement with its visual and sensory dimensions. At the same time, the presence of frustration in some participants (**Figure 4**) highlights the cognitive demands imposed by AR. Disruptions in perceptual coherence or interference with embodied interaction may lead to disorientation or reduced engagement, consistent with cognitive load theory and multimodal attention^[53]. Additionally, a significant proportion of participants (35.6%) report neither frustration nor strong satisfaction, suggesting that the AR performance did not substantially alter their perceptual or emotional experience. This may reflect design limitations (e.g., underwhelming interactivity or technical issues) or a mismatch between the medium and participants' perceptual habits.

Thus, these results support the view that augmented immersive theatre can foster active, embodied participation, but its effectiveness depends on how seamlessly the technological layer aligns with human cognitive and perceptual capacities. Both positive and neutral or frustrated responses reveal the sensitivity of immersive experiences to perceptual coherence, interactivity, and multi-sensory integration. They emphasize the importance of careful design to promote deep engagement and meaningful emotional responses.

4.3. Comfort, Novelty, and Technological Mediation

Several participants reported physical discomfort, technical limitations, or visual overload during the performance (**Table 5**), highlighting the tension between novelty and comfort in immersive technological environments (**Table 6**). While AR and interactive features can enrich the spectator experience, they also introduce cognitive and physical constraints that may influence attention, engagement, and overall perceptual integration. This interplay between technological innovation and user comfort emerg-

es as a key consideration for designing immersive performances that are both captivating and accessible, ensuring that technological augmentation supports rather than hinders understanding, learning, reflection, and retention.

The degree of novelty associated with the AR technology appeared to shape participants' expectations and perceptual engagement. Prior studies^[54] suggest that technological familiarity reduces cognitive load, allowing deeper sensorimotor engagement and memorization. In the present study, novelty likely contributed to heightened attention and curiosity but also to occasional strain or distraction, illustrating the delicate balance between stimulating immersion and overloading perceptual resources. Regarding comfort and wearability, **Table 6** indicates that most participants found the AR glasses tolerable, though they were not fully forgotten during the experience. This partial integration of the device may have limited the immersive effect, as spectators remained partly aware of the technological mediation. Such observations suggest that prior exposure to AR or interactive technologies can raise ergonomic expectations, particularly regarding comfort, weight, and visual clarity, which the current device may not have fully met. These findings underscore the important role of technological mediation in shaping immersive experiences. While AR and interactive elements can significantly enhance sensory engagement and the retention of environmental themes, they must be carefully balanced with user comfort. As a matter of fact, ergonomic and perceptual factors play a significant role in shaping engagement and immersion.

4.4. Immediate Awareness of Environmental Themes and Transformative Potential

While the concept of the eco-embodied spectator focuses on the corporeal and sensory integration of the performance environment, this section examines the extent to which immersive experiences influence participants' awareness, reflection, and engagement with environmental issues, drawing on both questionnaire responses and sociological data on young people's ecological attitudes.

4.4.1. Immediate Awareness and Sensitization

Evidence from participant feedback indicates that

elements of the performance were actively interpreted and remembered, particularly those linked to ecological and speculative themes. References to the Earth, decomposition, and transhumanism (**Table 3**) demonstrate that the augmented immersive environment supported cognitive encoding through embodied interaction. The novelty and transparency of the AR device appeared to facilitate engagement without significant distraction, resulting in memorable and emotionally resonant impressions. **Table 5** further shows that audience members recalled key visual effects directly related to environmental symbolism (e.g., soil decomposition, circles of light, “melting” earth), and most reported strong satisfaction with the experience. These findings suggest that AR-enhanced theatre can effectively support understanding and immediate sensitization to environmental themes through embodied participation.

4.4.2. Contextualization with Sociological Data

National surveys and studies provide additional insight into the potential impact of immersive theatre on French young audiences. For instance, the CAMME survey conducted by CEPREMAP^[55] and the Ipsos Survey on Young People and Science^[56] indicate that individuals under 35 consistently prioritize environmental preservation and biodiversity, often engaging in activism or participatory behaviors. Historical data from Ifop^[57] and ADEME^[58] further confirm that adolescents and young adults express stronger concern for climate change and ecological degradation compared to older age groups. In our sample, most participants (62.7%) were between 13 and 17 years old, aligning with these national trends and positioning youth as key actors of environmental awareness. This generational sensitivity provides a fruitful context in which augmented immersive theatre can potentially amplify engagement with ecological issues.

4.4.3. Potential for Transformative Impact

Beyond immediate comprehension, several participants reported cognitive and emotional responses suggestive of longer-term reflective engagement, including motivation for future action (e.g., joining an environmental association) and deeper contemplation of ecological

futures (**Table 5**). These observations highlight the transformative potential of immersive theatre as a space where audiences can confront and reflect on existential and environmental challenges. By linking embodied engagement with speculative environmental narratives, the performance demonstrates how augmented immersive theatre can create reflective, participatory learning environments, fostering both awareness and a disposition toward future action.

4.5. Pedagogical and Practical Implications

The findings of this study suggest that AR-enhanced immersive theatre offers significant opportunities to rethink both theatrical practice and pedagogical design. By demonstrating that embodied and enactive participation fosters simultaneous cognitive, emotional, and reflective engagement, this study highlights the potential of AR to transform traditional approaches to audience involvement and learning. These results are particularly relevant for educators seeking to integrate multi-sensory, participatory experiences into their teaching, as they point to new ways of facilitating deeper understanding of complex issues such as environmental awareness or speculative futures.

For theatre practitioners and designers, the findings reveal that technological augmentation can enhance immersion when it is meaningfully aligned with narrative and spatial design. Rather than treating AR as a purely aesthetic or technical addition, it should be considered a catalyst for co-creation and critical reflection, allowing audiences to actively construct meaning within the performance. For researchers, these results open up new possibilities for studying how knowledge is negotiated and retained in AR-augmented immersive environments, paving the way for comparative and longitudinal studies that examine the impact of embodied learning over time.

4.6. Study Limitations and Recommendations

Despite the insights gained from this study, several limitations must be acknowledged. First, the post-performance questionnaire was originally designed for non-scientific purposes and lacked standardized measures, which limits the robustness of statistical comparisons. In addition, the relatively small sample size, restricted to two school performances, constrains the generalizability of the

findings. Consequently, while the results – derived from post-performance questionnaires and preliminary observations of participants – provide initial indications of how augmented immersive theatre can influence perception and engagement, caution is warranted when extrapolating these outcomes to broader populations or different performance contexts.

Second, the questionnaire was administered immediately after the performances, which means that the study primarily captures participants' immediate awareness and sensitivity to environmental themes rather than long-term retention or behavioral change. Future research should incorporate delayed measures to determine whether the embodied and emotional engagement observed translates into sustained awareness, reflection, or active participation in ecological initiatives. Such a longitudinal assessment would provide a clearer understanding of the potential transformative impact of augmented immersive theatre.

A third limitation arises from the use of a specific technological setup, namely AR glasses, which may have introduced novelty effects influencing reported immersion and engagement. As shown in **Figure 2** and **Table 7**, the device itself may have interfered with flow and continuous bodily integration, highlighting the decoupling of physical comfort from technological receptivity. This phenomenon likely reflects the curiosity-driven nature of the immersive encounter: the promise of a new sensory experience can momentarily outweigh ergonomic constraints. From a cognitive and embodied perspective, this observation aligns with theories suggesting that sensory salience and attentional arousal, particularly in unfamiliar or multi-layered environments, can override bodily discomfort and foster heightened engagement, at least in the short term^[59].

Physical and cognitive limitations were also evident. Nearly half of the participants (47.5%) reported eye strain or other forms of physical discomfort (**Table 2**), representing the primary barriers to sustained immersion. Cognitive and physiological overload appears to explain why many participants intermittently removed the AR glasses, highlighting the paradox of augmented immersive theatre: while the body serves as the gateway to immersion, it can simultaneously act as a site of resistance when sensory demands exceed comfort thresholds. Discrepancies between visual, vestibular, and proprioceptive cues (such as mis-

alignment of AR layers with the physical environment) can further impede full sensorimotor integration, especially for participants unfamiliar with AR technology. Indeed, novel sensory input may increase cognitive load and reduce the capacity to fully integrate environmental narratives, thereby limiting both engagement and the depth of reflective processing.

Finally, participant feedback pointed to opportunities for improving accessibility, comfort, and technological integration. Suggestions included enhancing the ergonomics of AR devices, optimizing visual and auditory stimuli, and minimizing distractions arising from the interplay of live performance and augmented layers. Addressing these issues is essential to maximizing engagement and learning outcomes and will ensure that immersive experiences maintain both educational value and experiential effectiveness.

Building on these insights, several practical recommendations can be made for effectively integrating AR into immersive theatre as a pedagogical tool. First, ensuring physical comfort and accessibility is essential: AR devices should be lightweight, ergonomically designed, and inclusive to accommodate diverse audiences and prevent fatigue or discomfort. Second, designers should balance novelty and familiarity, ensuring that AR supports rather than overshadows the narrative, thereby enhancing comprehension and engagement without causing cognitive overload. Third, immersive experiences should be multi-sensory, coherent, and combine visual, auditory, and interactive elements in ways that reinforce embodied learning and facilitate the understanding and memorization of complex themes. Fourth, AR should encourage active participation and reflection, enabling audiences to explore, make choices, and engage both bodily and cognitively with the performance to foster enactive learning on topics such as environmental crises and possible futures. Finally, complementing performances with post-experience discussions, questionnaires, or learning resources can support knowledge retention and extend reflection beyond the performance itself. Collectively, these recommendations emphasize that, when carefully designed with both engagement and educational objectives in mind, AR-augmented immersive theatre has significant potential as an innovative and impactful tool for learning.

5. Conclusions

This study highlights the potential of AR immersive theatre to engage audiences with complex environmental themes in ways that extend beyond conventional educational approaches. By combining live performance with technological augmentation, such experiences create multi-sensory environments that activate participants' cognitive, emotional, and bodily engagement simultaneously. The responses to the post-performance questionnaire suggest that participants' embodied involvement facilitated an awareness of environmental issues and supported understanding of the core themes explored in the performance. While individual responses varied, many participants reported moments of profound connection and reflection, suggesting that immersive theatre can foster meaningful engagement with ecological challenges.

The analysis of participants' reflections also underscores the importance of the quality and coherence of the immersive experience. Factors such as the clarity of the narrative, the orchestration of exteroceptive and proprioceptive cues, and participants' openness to emotional and imaginative resonance influenced how deeply they engaged with the environmental content. Conversely, occasional interoceptive discomfort or visual saturation limited engagement for some individuals, highlighting the need for careful calibration of sensory, spatial, and technological elements. These findings suggest that the effectiveness of augmented immersive theatre relies not solely on technological novelty but on the integration of sensory, narrative and participatory dimensions that collectively foster reflection, affective resonance and deeper understanding.

The metaphors and imagery reported by participants, such as "germination" and "other possible worlds" — which is a possible translation of the play's title in English — illustrate how augmented immersive theatre can stimulate imaginative and affective processes. These metaphors evoke slow, organic transformations and the exploration of alternative futures, pointing to the capacity of theatre to encourage audiences to reconsider their relationship with the environment and imagine ethical and sustainable possibilities. Such experiences, while not uniform across all participants, indicate that immersive theatre can trigger subtle shifts in perception and affective disposition that may continue to develop over time.

This alignment of perception, action and emotion resonates with the Augmented Enactive Learning (AEL) methodology, which emphasizes that knowledge emerges through the dynamic interplay between body, mind, and environment. From this perspective, augmented immersive theatre provides a context where participants do not merely receive information but enact it through their sensorimotor engagement and emotional resonance. Such experiences can therefore support deeper forms of meaning-making, where understanding is grounded in lived, embodied participation rather than abstract conceptualization. Moreover, the participatory nature of these experiences encourages a sense of agency and personal involvement, which may strengthen the relevance and memorability of the content presented.

Future studies could therefore examine the long-term impact of augmented immersive theatre on participants' knowledge retention, emotional engagement, and reflective capacities. Expanding research to include diverse age groups, cultural contexts, and educational settings would help determine how universally applicable these experiences are. Comparative studies across different forms of immersive environments (such as XR simulations and installations) could also clarify which technological and narrative elements most effectively foster engagement and understanding. In addition, combining qualitative measures of experience with quantitative assessments of learning outcomes could provide a more comprehensive picture of the educational potential of immersive performances. Finally, exploring the interplay between sensory, emotional, and cognitive dimensions in immersive experiences may offer valuable insights for designing performances that maximize both affective resonance and cognitive impact, thereby supporting transformative engagement with complex societal challenges such as environmental crises.

Funding

This work received no external funding.

Institutional Review Board Statement

Ethical approval was not required for this study as the questionnaires were completed anonymously.

Informed Consent Statement

Verbal informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The datasets generated and analyzed during the current study are available on the Huma-Num data-sharing platform [<https://sharedocs.huma-num.fr/#/HOME>]. Access to the data may be subject to the platform's terms and conditions.

Acknowledgments

The author acknowledges the support of Anaïs Bourgeois and Théâtre Nouvelle Génération for passing on the results of the questionnaires. She is also grateful to Nicolas Molle, PhD in English studies, for his validation of the translation of the questionnaire, and to Mathieu Bréauté, computer engineer, for his meticulous review of the manuscript and his technical insights.

Conflicts of Interest

The author declares no conflict of interest.

Appendix A

This questionnaire was distributed to the participants immediately after the performance of the AR play *La Germination, D'autres mondes possibles* (Episode 1) in November 2023 to get audience feedback on AR Glasses.

The original questionnaire and its corresponding responses were in French. For the purposes of this article, they have been translated into English by the author and validated by Nicolas Molle, PhD in English studies at the Université de Lorraine, Nancy, France.

The audience members were informed as follows: "This questionnaire will take less than five minutes. If you wish to change an answer you have already selected, please circle your final choice."

1. Age:
 - 13 – 17 years
 - 18 – 24 years
 - 25 – 35 years
 - 36 – 45 years
 - 46 – 65 years
 - Over 65 years
2. Have you previously had the opportunity to use a virtual reality headset?
 - Yes
 - No
 - Don't know
- 2a. If so, was it for a performance, exhibition, or another use, such as video games?
 - Performance
 - Exhibition
 - Other
3. Have you previously had the opportunity to use augmented reality glasses?
 - Yes
 - No
 - Don't know
- 3a. If so, was it for a performance, an exhibition, or another use such as (games or video)?
 - Performance
 - Exhibition
 - Other
4. How often do you attend dance and/or theater performances?
 - Very often
 - Often
 - Occasionally
 - Almost never
 - Never
5. Would you say that wearing the augmented reality glasses was rather comfortable or uncomfortable?
 - Very comfortable
 - Quite comfortable
 - Not comfortable, but not uncomfortable
 - Quite uncomfortable
 - Very uncomfortable
6. Did you keep the glasses on during the entire performance?
 - Yes
 - No
 - I occasionally lifted them
- 6a. If you didn't keep them on or lifted them occasional-

- ly, could you explain why?
[Open answer]
7. Did you experience technical issues while viewing the virtual images?
- Yes, many
 - Yes, a little
 - No
 - I don't know
- 7a. If so, did rescanning the posters solve the issue(s)?
- Yes, every time
 - Yes, but not always
 - No
- 7b. If not, can you describe the issue you encountered?
[Open answer]
- 7c. And if you were unable to solve the issue, did you completely remove the glasses?
- Yes, but after several attempts to resolve the problem
 - Yes, after a single attempt to fix the issue
 - No, I kept them on
8. Did you experience eye fatigue during the performance?
- Yes, a lot
 - Yes, a little
 - Yes, a little, but without too much inconvenience
 - No, not really
 - Not at all
9. Do you wear prescription glasses?
- Yes
 - No
- 9a. If you wear prescription glasses, what vision problems do they correct?
- Myopia
 - Astigmatism
 - Hyperopia
 - Presbyopia
10. Did the ability to see the stage and performers directly through the transparent lenses while also seeing virtual images seem new to you?
- Yes, absolutely
 - Yes, a little
 - No, not really
 - No, not at all
11. Would you say that wearing the AR glasses and seeing virtual images at the same time pulled you out of the performance?
- Not at all
 - Very slightly
 - Moderately
 - A lot
 - Very much
12. During the performance, did you often pay attention to the behavior of other audience members?
- Often
 - Sometimes
 - Once
 - Never
13. Did this mode of augmented reality performance cause you frustration (by watching the show through a filter), or cause you satisfaction (by providing an enhanced universe)?
- A great deal frustration
 - Slight frustration
 - No frustration, no satisfaction
 - Slight satisfaction
 - High satisfaction
14. Was there a particular staging or visual effect in the performance that you especially liked or found striking?
- Yes
 - No
- 14a. If so, which one?
[Open answer]
15. Was there a particular staging or visual effect in the performance that you especially disliked or found disturbing?
- Yes
 - No
- 15a. If so, which one?
[Open answer]
16. Do you have any additional comments you would like to share with us?
[Open answer]

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