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Modeling Environmental Awareness through Narrator-based Timeline Simulations of Environmental Events

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Abstract: This study explores the development of environmental awareness models by employing narrator-based timeline simulations of significant environmental events. The research emphasizes how immersive narratives, structured according to historical and hypothetical timelines, can improve the individual and collective understanding of environmental challenges. Simulating key moments such as industrialization, environmental disasters, and political advances. This study aimed to investigate the development of environmental awareness models through timeline simulations based on the narratives of environmental events. The methodology integrates storytelling with scientific data to contextualize environmental issues, encouraging emotional engagement and critical reflection.

Findings indicate that these simulations promote deeper awareness of sustainability issues, encouraging proactive behaviors and informed decision making. The study contributes to environmental education by highlighting the potential of narrative-based simulations as innovative tools to generate environmental awareness and encourage actions toward ecological resilience.

Keywords: Models, environmental awareness, timeline storyteller, simulations, environmental education

通过基于叙述者的环境事件时间线模拟来建模环境意识

摘要：本研究通过采用基于叙述者的重大环境事件时间线模拟，探索环境意识模型的发展。研究强调了根据历史和假设时间线构建的沉浸式叙述如何提高个人和集体对环境挑战的理解。模拟工业化、环境灾难和政治进步等关键时刻。本研究旨在通过基于环境事件叙述的时间线模拟来研究环境意识模型的发展。该方法将讲故事与科学数据相结合，以将环境问题情境化，鼓励情感参与和批判性反思。研究结果表明，这些模拟促进了对可持续性问题的更深入认识，鼓励积极主动的行为和明智的决策。该研究通过强调基于叙述的模拟作为激发环境意识和鼓励生态复原力行动的创新工具的潜力，为环境教育做出了贡献

关键词：模型、环保意识、时间轴讲述者、模拟、环境教育

1. Introduction

Environmental awareness is a critical aspect of addressing global ecological challenges. It involves understanding the interplay between human activities and environmental systems and fostering informed decision-making and sustainable practices. Over the years, various models have been developed to enhance environmental awareness, ranging from cognitive frameworks to behavioral approaches. Among these, simulation-based methodologies have gained traction because of their immersive and experiential learning potential, enabling participants to engage with complex environmental phenomena in controlled scenarios [1, 2].

Narrator-based timeline simulations have shown that combining narratives and visual simulations improves emotional engagement and facilitates long-term knowledge retention [6, 24]. These simulations allow participants to actively experience the consequences of environmental decisions, reinforcing the cognitive, affective, and behavioral dimensions of learning [27, 28]. Additionally, they allow students to analyze multiple perspectives on environmental challenges by simulating real-world complexities in a structured and interactive format [24]

By integrating storytelling with chronological sequences of environmental events, this approach provides participants with a compelling narrative that summarizes historical, present, and hypothetical future scenarios. These simulations allow individuals to navigate key moments, such as industrial revolutions, historic environmental policies, and catastrophic ecological disasters, fostering a deeper emotional and intellectual connection with the material [27, 28]. The ability of timeline-based simulations to contextualize abstract environmental issues in an engaging and identifiable format makes them particularly valuable for educational interventions in sustainability and environmental awareness.

Narrator-based timeline simulations represent an innovative approach to environmental awareness. By integrating storytelling with chronological sequences of environmental events, this method provides participants with a compelling narrative that encapsulates historical, present, and hypothetical future scenarios. Such simulations allow individuals to traverse key moments, such as industrial revolutions, landmark environmental policies, and catastrophic ecological disasters, fostering a deeper emotional and intellectual connection with the material [3, 21].

This approach builds on the narrative's capacity to make abstract environmental issues relatable by combining descriptive storytelling with scientifically grounded data. Narratives are powerful tools for learning because they activate emotional engagement, enhance memory retention, and facilitate the understanding of cause-effect relationships over time [4]. Moreover, timeline-based simulations provide a structured progression, helping participants understand the evolution of environmental challenges and the cumulative impact of human actions on ecosystems [5].

The potential of narrator-based simulations extends beyond awareness; they seek to inspire proactive behavior by embedding lessons within lived experiences, albeit virtual. Studies have shown that such methodologies are effective in bridging the gap between knowledge and action, particularly when addressing complex, long-term environmental issues like climate change and biodiversity loss [6].

This study investigates the use of narrator-based timeline simulations in developing models of environmental awareness. This study explores how integrating historical narratives with scientific projections can foster a transformative understanding of sustainability challenges, ultimately influencing individual and societal behavior toward environmental stewardship.

Considering the above-mentioned findings, this study identifies three key research questions, which are outlined below:

RQ1. How do the dynamics of emotional engagement and their relationship to the critical moments of the simulation vary, based on the Timeline Storyteller radial representation?

RQ2. What temporal progression is observed in students' knowledge and behavioral intention across the interventions, based on the chronological scale?

RQ3. What differences emerge between students in terms of knowledge, emotional engagement, and behavioral intention, based on the faceted comparison by groups or categories?

The analysis using Timeline Storyteller tools seeks to delve deeper into the evolution of environmental awareness models following the intervention with the EN-ROADS climate simulator, addressing three key dimensions. Through the radial representation, we aim to identify cyclical patterns in students' emotional engagement, especially in response to simulated critical moments, such as the rise in global temperature. With the chronological scale, we explored the temporal progression of knowledge and behavioral intention, observing how these variables evolve throughout the interventions and highlighting the points of greatest educational impact.

Finally, faceted representation allows for comparing individual and group responses, analyzing how initial differences in levels of environmental awareness influence changes experienced during the process. This approach seeks to reveal both general trends and specific nuances that enrich the understanding of the impact of interactive and narrative tools on environmental education.

2. Materials and Methods

This research employed a mixed-methods approach, integrating quantitative assessments and qualitative insights to evaluate the effectiveness of narrator-based timeline simulations in fostering environmental awareness. Mixed methodologies allow researchers to bridge the strengths of quantitative precision with the depth of qualitative insights [7]. The study design included the development, implementation, and evaluation of a simulation program structured around key historical and hypothetical environmental events.

2.1 Simulation Framework

The simulations were created as storyteller-led experiences, offering participants an immersive journey through significant environmental events. The framework included:

-Historical Events: Moments such as the Industrial Revolution and the Kyoto Protocol, as understanding the past is pivotal for contextualizing present environmental challenges [8].

-Contemporary Scenarios: Topics like urban pollution and deforestation reflect the urgent realities of current ecological crises [9].

-Hypothetical Futures: Scenarios based on predictive models align with the assertion that exploring plausible future fosters critical thinking and anticipatory learning [10].

The simulations were implemented using Climate Interactive En-ROADS Simulator, a tool grounded in system dynamics modeling and systems thinking. En-ROADS allows users to harness the power of experiential learning to engage and inform people about high-impact, equitable climate solutions [11]. Its interactive platform enabled participants to explore environmental dynamics through real-time feedback, visualizations, and scenario-based decision-making. (see Figure 1).

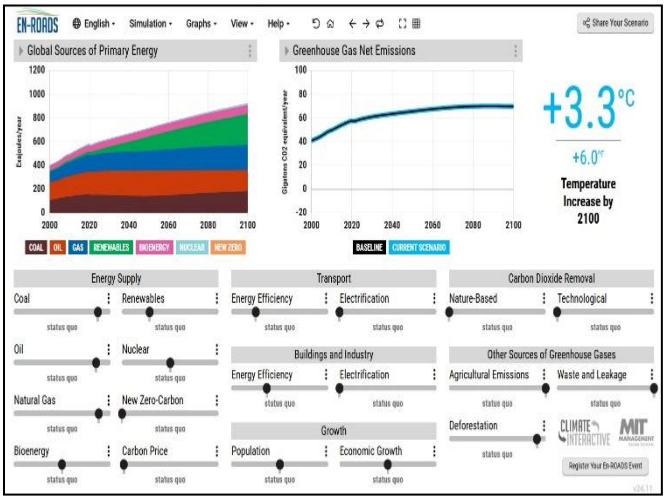


Figure 1. EN-ROADS (developed by the authors)

The EN-ROADS scenario presented shows a simulation of global climate outcomes under the status quo, settings for various factors affecting climate change, such as energy supply, transportation, carbon dioxide removal, and economic growth. Key insights include:

A). Energy Sources: A continued reliance on fossil fuels (coal, oil, and natural gas) dominates the global energy supply, with limited growth in renewable energy and other low-carbon options.

B). Emissions: Greenhouse gas emissions rise steadily, reflecting minimal mitigation efforts, leading to significant warming.

C). Temperature Impact: The global temperature increase is projected to reach **+3.3°C by 2100**, far above the 1.5°C or 2°C targets set by the Paris Agreement. This scenario highlights the need for stronger policy actions and technological interventions to shift away from fossil fuels and implement more sustainable practices globally.

2.2 Participants

The study included 27 university students from the fourth semester of undergraduate studies in the environmental engineering program of the Central Unit of Valle del Cauca, Colombia. These students allow them to contribute their reflections in the academic context, which aligns with research that suggests that diverse educational origins enrich the interpretive lens of environmental education [12].

2.3 Data Collection

Pre- and Post-Simulation Surveys: Structured questionnaires measured participants' baseline knowledge, emotional engagement, and behavioral intentions before and after the simulation. The surveys included Likert-scale items and open-ended questions to assess changes in awareness and perspectives. The structured assessments are essential for quantifying the educational impact of interactive tools [13].

Observation and Interaction Logs: Participant interactions during the simulations were recorded, including decisions made and time spent on specific tasks. These data points provided insights into the engagement and comprehension levels how interactive tasks facilitate deeper engagement with complex issues [14].

Focus Group Discussions: Post-simulation, participants engaged in focus group discussions to reflect on their experiences, providing qualitative data on the emotional and intellectual impact of the simulations. The narratives can evoke emotional resonance, making environmental challenges more relatable [15].

2.4 Data Analysis

The quantitative survey results were analyzed using paired t-tests, as statistical comparisons are vital to identifying significant shifts in awareness and behavior [15]. Qualitative data from the focus groups were thematically coded using Atlas.ti(ver.25) and Power BI software with the Timeline Storyteller visual allowing for the extraction of meaningful patterns from reflective feedback [16]. See Table 1.

Table 1. Impact analysis of the intervention on the key variables of environmental awareness (compiled by the authors)

Variable	Pre-Mean (SD)	Post-Mean (SD)	Mean Difference	t-value	p-value
Knowledge	4.98 (1.03)	8.22 (0.73)	3.24	-12.94	0.000
Emotional Engagement	6.16 (1.53)	8.87 (0.78)	2.72	-7.68	0.000
Behavioral Intention	5.46 (1.39)	7.84 (1.11)	2.37	-6.22	0.000

Explanation of Table 1:

1.Knowledge: The mean increased significantly after the simulation, with a large t-value and a p-value of 0.000, indicating a substantial improvement.

2. Emotional Engagement: The simulation also significantly boosted participants' engagement, as reflected in the positive mean difference.

3. Behavioral Intention: There was a significant increase in behavioral intentions to act on climate-related issues.

This table demonstrates that the simulation significantly improved knowledge, emotional engagement, and behavioral intentions among the 27 participants. All changes were statistically significant ($p < 0.05$), confirming the effectiveness of the simulation

3. Results

3.1 Design Space

The results indicate a statistically significant increase in environmental knowledge, emotional engagement, and behavioral intention among the participants. The emotional engagement dimension showed peak responses during critical simulation moments, aligning with theories that suggest emotions drive behavioral change [23, 28]. The timeline representation demonstrated a linear progression in knowledge acquisition, reinforcing the role of structured experiential learning in sustainability education.

Moreover, the faceted analysis revealed that students with lower initial knowledge showed the highest gains, supporting findings from previous research indicating that interactive simulations are particularly impactful for individuals with minimal prior exposure to environmental topics [6, 22]. Additionally, group-based reflection session post-simulation played a crucial role in consolidating behavioral intentions, suggesting that social learning dynamics enhance the long-term effectiveness of environmental education interventions.

The Timeline Storyteller workspace allows you to structure events into linear, radial, spiral, grid, or clustered representations, making it easier to understand patterns, cycles, and relationships between events over time. It integrates quantitative and qualitative data, prioritizing both visual clarity and the ability to tell data-driven stories [17]. See Figure 2.

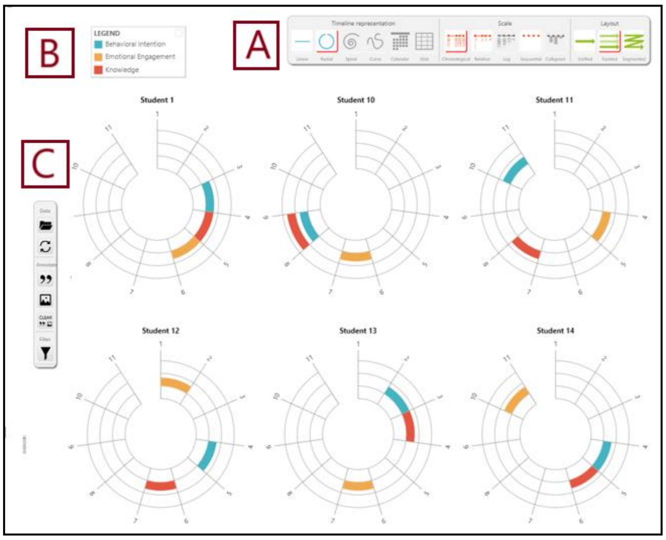
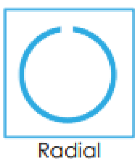


Figure 2. Space timeline storyteller-impact result of the intervention – pre-mean (developed by the authors)

Figure 2 presents the workspace, made up of the following dimensions: (A) toggles for alternative timeline representations, scales, and layouts; (B) a movable event legend; (C) widgets for loading data, annotating the canvas with captions and images, filtering and highlighting events, and exporting content.

3.1.1 Dimension 1: Timeline Representation

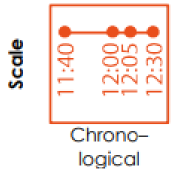
The Timeline representation in the Timeline Storyteller tool is used to choose how information is organized and visually displayed on the timeline, adapting to the purpose of data analysis and communication (Figure 2). The RADIAL representation shows the cyclical patterns of the students'



environmental awareness models in their first instance, considering the themes of knowledge, emotional commitment and behavioral intention.

3.2 Dimension 2: Scale

The Scale dimension is used to adjust how events are distributed along the timeline based on the relationship between time and data. This setting allows you to change the perception of the time interval, highlighting certain events or periods. In Figure 2, the Chronological scale is selected. This scale is used to represent time in a graph or visualization in a proportional and organized way, adjusting how events or data are distributed in relation to the passage of time.

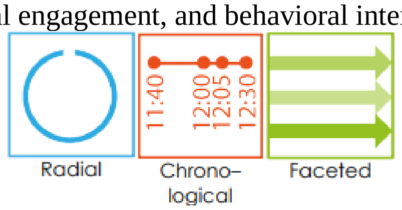


3.3 Dimension 3: Layout

The Layout dimension refers to how the visual elements of the timeline are organized in the chart space. It serves to adapt the presentation of events according to the type of story you want to tell and the characteristics of the data. In Figure 2, the Faceted layout is selected. It is used to divide the timeline into several sub-lines or panels based on a specific category. This layout allows you to compare multiple series of events or analyze segmented data according to attributes such as categories, groups, or individuals, while maintaining an orderly and clear layout.

The study used the EN-ROADS climate simulator along with the Timeline Storyteller visualization tool with three key dimensions: radial, chronological, and faceted.

Visualization dimensions. All three visualization dimensions highlighted patterns, which allowed for the identification of significant patterns in knowledge, emotional engagement, and behavioral intention.



In the radial dimension, recurrent cycles in emotional engagement were evident, especially associated with interaction with critical scenarios such as the 2°C increase in global temperature. The chronological representation showed a linear progression in knowledge, which increased steadily as students understood the impact of their decisions in the simulator, while behavioral intention was consolidated toward the final stages, when participants proposed measures applicable to their local context.

On the other hand, the faceted dimension allowed the comparison of the evolution of these variables between different students, showing that those with less initial knowledge experienced the greatest increases in all dimensions. In addition, it was observed that emotional engagement was greater in students who actively participated in group discussions, highlighting the influence of social interaction on environmental learning. This visual and narrative approach facilitated a deeper understanding of the changes generated by the simulations and reaffirmed the potential of interactive tools such as EN-ROADS to promote environmental awareness and encourage sustainable behaviors.

Through the dimensions of radial, chronological and faceted visualization, the post-intervention impact on the variables of knowledge, emotional commitment and behavioral intention was analyzed. See Figure 3.

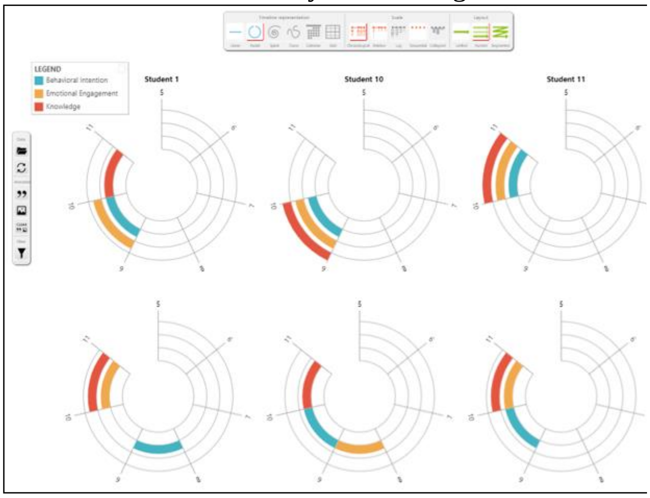


Figure 3. Impact result of the intervention-post mean (developed by the authors)

The resulting model after the intervention based on the EN-ROADS climate simulator and analyzed through the three dimensions of Timeline Storyteller visualization—radial, chronological, and faceted—showed a significant impact on students' environmental awareness patterns. In the post-intervention (Post-Mean) analysis, a general increase was observed in the dimensions of knowledge, emotional engagement, and behavioral intention. The radial representation revealed a cyclical pattern in emotional engagement, with peaks coinciding with the moments when students faced critical scenarios, such as the increase in global temperature beyond the 1.5°C limit. This highlighted the capacity of simulated events to generate emotional reactions that catalyze deeper reflections on environmental issues.

The chronological representation, on the other hand, allowed us to analyze the linear progression of the variables during the intervention time. The results showed that the students' knowledge increased steadily as they interacted with the simulator and understood the consequences of policies such as carbon taxes or the transition to renewable energy. The behavioral intention, although less pronounced at the beginning, was consolidated in the final stages of the simulation, especially after group discussions in which participants proposed concrete actions to mitigate the environmental impact in their local communities [20]. This suggests that the timing of the interventions and joint reflection are key elements in the formation of sustainable intentions.

Finally, the faceted model allowed for comparisons of results between different groups of students, highlighting differences in individual responses to the simulations. Those with lower initial levels of knowledge experienced the greatest increases in all three dimensions, while emotional engagement was highest in participants with greater involvement in group dynamics.

4. Discussion

Analysis of environmental awareness models using Timeline Storyteller revealed important patterns in the evolution of cognitive, emotional and behavioral dimensions after the intervention with the EN-ROADS climate simulator. In the radial representation, cyclical patterns in emotional engagement were identified, especially linked to critical moments of the simulation, such as the increase in global temperature beyond the safe limit of 1.5°C. These findings are consistent with those reported in [18], claiming that interactive simulations can generate strong emotional responses by making projected climate risks tangible. Such emotions are essential to catalyze changes in environmental perception and strengthen the affective connection with ecological problems.

The findings of this study align with those reported by [22], who demonstrated that interactive simulation foster increased environmental awareness. However, while their approach primarily focused on quantitative climate modeling, this study integrates narrative elements, which have been found to enhance emotional engagement and personal relevance [27, 29]. See Table 2.

In addition, unlike traditional lecture-based environmental education [24], this research shows that immersive storytelling strengthens both cognitive and affective learning. Furthermore, compared to [27], who noted that emotions triggered by simulations might be transient, this study suggests that the combination of interactive storytelling and structured reflection can sustain long-term behavioral change.

The comparison of the analyzed studies reveals diverse strategies to promote environmental awareness, each with its own strengths and limitations. Quantitative simulations such as EN-ROADS were employed in [22]; these simulations generate an increase in environmental awareness, although with a moderate emotional impact.

In contrast, the study on narrative timeline simulations seeks to intensify emotional engagement, which could generate a more sustained attitude change.

From the perspective of experiential learning, [24] emphasizes the importance of immersion and practice in learning, something that is reflected in the structure of narrative simulations, where participants can interact with environmental events in a narratively constructed timeline. This alignment with experiential learning reinforces the idea that emotional connection and subjective experience are key in building environmental awareness models.

Table 2. Comparison of the current study with previous research (compiled by the authors)

Study	Methodology	Key Findings	Comparison with the Present Study
Rooney-Varga et al. [6]	Quantitative simulation (EN-ROADS)	Increased awareness, moderate emotional impact	This study integrates narratives to enhance emotional engagement
Kolb [25]	Experiential learning models	Supports immersive, hands-on learning	Findings align with the experiential nature of the timeline simulations
Bowers [26]	Environmental education analysis	Emphasizes emotional response but notes transience	The current study suggests combining storytelling with reflection for sustained impact
Kongson [28]	The STSE model was employed to facilitate activities centered on the identification of environmental issues, the formulation of solutions, decision-making processes and community engagement.	The STSE model’s interactive and problem-solving approach, which incorporates real-life environmental issues, proved to be an effective method of engaging students in learning and raising their environmental consciousness.	The study found that the STSE model, by integrating real environmental problems, improves students’ environmental awareness. Its interactive, problem-solving approach encourages engagement, motivation, and meaningful learning.

On the other hand, [25] warns that emotion-based environmental education can be transitory, which poses a challenge for the consolidation of changes in environmental awareness in the long term. However, the study of narrative simulations incorporates reflection as a strategy to mitigate this effect, promoting a deeper internalization of learning.

The STSE model approach, analyzed in [28], integrates problem solving and community participation, highlighting the value of active and contextualized learning. Although this model emphasizes decision making and the identification of real environmental problems, the study of narrative simulations in a timeline provides an immersive and affective dimension that complements this approach.

Taken together, the reviewed studies show that environmental awareness can be fostered through multiple approaches. While quantitative simulations offer an analytical and predictive basis, narrative strategies strengthen the emotional and experiential dimension. The combination of these approaches could generate a deeper and longer-lasting impact on students’ environmental awareness by integrating reflection, emotion and problem solving in the same learning process.

From a chronological perspective, the temporal progression of the variables evidenced a sustained growth of environmental knowledge as students interacted with the simulator and understood the consequences of different climate policies, such as carbon taxes or energy transition. This result supports previous research highlighting the pedagogical value of dynamic tools in environmental education [19]. Furthermore, behavioral intention showed a more gradual development, consolidating toward the end of the interventions, when students had the opportunity to propose specific actions in their local contexts. This effect could be related to Ajzen’s theory of planned action [23], which suggests that knowledge must be complemented with reflection and deliberation to translate into intention to act.

The faceted representation allowed for a comparison of individual and group responses, revealing that students with lower initial levels of environmental knowledge experienced the largest increases across all dimensions. This finding is consistent with Kolb’s observations [25], which underline the importance of immersive and reflective experiences to bridge cognitive and emotional gaps. Furthermore, emotional engagement was higher among students who actively participated in group discussions, highlighting the role of social dynamics in shaping environmental awareness patterns. Social interaction appears to amplify emotional responses and foster greater ownership of the issues addressed.

Taken together, these findings underline the effectiveness of tools such as EN-ROADS and Timeline Storyteller in environmental education, not only for their ability to convey complex information but also for their potential to generate emotional impact and promote collective reflections. However, it is important to consider the possibility of biases in emotional responses or differences in learning styles between students, suggesting the need for future studies that analyze these variables in greater depth. This methodological and narrative approach represents a significant contribution to the design of educational strategies focused on changing environmental awareness.

Despite the positive results obtained in the study, it is important to acknowledge the limitations and possible criticisms of the approach adopted. While tools such as EN-ROADS and Timeline Storyteller demonstrate high educational potential, their effectiveness may be conditioned by external factors, such as the initial predisposition of students, their interest in environmental issues, and their ability to interpret complex visualizations. Research such as that of Bowers [26] warns that emotional responses generated by simulations may be transitory and do not always lead to sustained change in behavior. Furthermore, the reliance on group dynamics to foster emotional engagement could limit the impact on students with less social participation, suggesting that interventions should be complemented with individualized strategies that consider the diversity of learning styles and levels of prior knowledge. This approach invites us to reflect on the need to combine technological tools with adaptive pedagogical approaches to maximize their impact.

The findings of this research can be applied beyond the university setting, offering potential contributions to sustainability education in policy-making, curriculum design, and community-based environmental programs. Studies have shown that experiential learning through simulations can be particularly effective in shaping behaviors when combined with reflective practices and active discussions [23, 29]. Furthermore, interactive simulations have been increasingly adopted in professional training programs for environmental policymakers and corporate sustainability initiatives, underscoring their versatility in diverse learning contexts [6].

5. Conclusion

The use of the Timeline Storyteller visualization tool in combination with the EN-ROADS climate simulator allowed us to innovatively explore the evolution of environmental awareness models in environmental engineering students. This methodological approach highlighted the importance of integrating interactive technologies and visual narratives to address complex issues, such as climate change, in educational settings. The results reflected a significant impact on the dimensions of knowledge, emotional engagement, and behavioral intention, evidencing how simulations based on temporal narratives can foster a deeper understanding and a more sustained commitment to environmental sustainability.

Through the radial representation, cyclical patterns were identified that highlighted the influence of simulated critical events on students' emotional engagement. On the other hand, the chronological scale showed a linear progression in knowledge and behavioral intention, underlining the relevance of structuring educational interventions in phases that allow for both knowledge acquisition and reflection and action. Furthermore, the faceted dimension revealed important differences between participants, highlighting the need for personalized approaches that address individual and group characteristics to maximize learning and emotional impact.

However, the study also highlights the need to consider the limitations in the implementation of these tools. Factors such as the initial predisposition of students and the dependence on group dynamics pose challenges to guarantee equity in the educational impact. Likewise, the possible transience of emotional responses requires exploring complementary strategies that reinforce the sustainability of changes in environmental awareness models. These findings invite future research that integrates narrative tools with adaptive and longitudinal pedagogical approaches to evaluate how changes in environmental awareness translate into sustainable actions over time.

In conclusion, this study highlights the value of combining interactive simulations with visual narratives to transform environmental awareness models in educational contexts. By addressing both the cognitive and emotional aspects of environmental education, these tools represent a significant advance in sustainability education. However, to maximize their impact, it is essential to continue researching their effectiveness in diverse contexts and populations and to develop comprehensive strategies that combine technology, pedagogy, and practical action. This approach can significantly contribute to the formation of more aware citizens committed to building a sustainable future.

Declarations

Author Contributions

Conceptualization, H.R. and L.C.P.V; methodology, H.R and A.R.P; software, H.R and A.R.P; validation, H.R, O.E.T.A. and A.R.P; formal analysis, H.R, A.R.P and L.C.P.V investigation, H.R.; resources, H.R. and L.C.P.V; data curation, H.R. and A.R.P; writing—original draft preparation, H.R. and L.C.P.V; writing—review and editing, H.R., A.R.P and L.C.P.V ; visualization, H.R and O.E.T.A; supervision, H.R and

A.R.P; project administration, H.R.; funding acquisition, H.R. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are available upon request from the corresponding author.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Committee of the Central Unit of Valle del Cauca, Colombia.

Informed Consent Statement

Informed consent was obtained from all the subjects involved in the study.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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