Einstein's Delivery: Bridging the Gap in Special Relativistic Education Through Digital Games

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Abstract. Introduction: *Teaching Special Relativity poses well-known pedagogical challenges due to its counterintuitive nature and high level of abstraction, often limiting students' conceptual understanding.* ***Objective:*** *This work presents Einstein's Delivery, a Digital Educational Game (DEG) designed to support the learning of Special Relativity concepts through interactive and contextualized gameplay.* ***Methodology:*** *The game was developed as a 2D platformer that simulates a "ludic world" in which the speed of light (c) is reduced, enabling players to experience phenomena such as time dilation and the Doppler effect as core mechanics. A heuristic evaluation was conducted to analyze usability, pedagogical alignment, and the clarity of feedback provided to learners.* ***Results:*** *The results suggest that the game has the potential to support the understanding of abstract physics concepts by connecting gameplay mechanics to scientific principles. Although findings indicate contributions to engagement and conceptual learning, the current version is a prototype and requires further validation in classroom contexts to assess its educational effectiveness and scalability.*
Keywords *Digital Educational Games, Game-Based Learning, Physics Education, Special Relativity, Scientific Literacy.*

1. Introduction

The teaching of Modern Physics, particularly the Theory of Special Relativity, poses significant pedagogical challenges in contemporary education [Blumetti et al. 2025]. Special Relativity remains one of the most challenging topics for students due to its inherently counterintuitive nature, which contradicts everyday intuition. Since relativistic effects such as time dilation, length contraction, and the Doppler effect—only become perceptible at velocities approaching the speed of light (3×10^8 m/s), they lie entirely beyond human sensory experience [Chu et al. 2019]. As a result, students often struggle to construct meaningful conceptual models that connect formal equations to physical reality. Traditional instructional approaches have historically relied on abstract mathematical derivations or complex thought experiments, which are frequently insufficient to support intuitive understanding, particularly at the high school and early undergraduate levels. This limitation reinforces a persistent gap between formal representations and conceptual understanding, making Special Relativity often perceived as inaccessible to learners [Chu et al. 2019].

In response to these challenges, Digital Educational Games (DEGs) have emerged as promising tools for supporting learning through Game-Based Learning (GBL) approaches [Voulgari 2020]. By providing interactive and engaging environments, these systems enable the simulation of ludic worlds, in which physical constants can be manipulated, allowing abstract scientific concepts to be experienced as gameplay mechanics [Boffi et al. 2024]. Within this context, DEGs can contribute to scientific literacy by fostering active exploration and experiential learning, enabling students to engage with phenomena that would otherwise be inaccessible.

However, despite their potential, there are still a limited number of approaches that explicitly integrate Special Relativity principles into game mechanics in ways that support conceptual understanding. In particular, the transformation of relativistic phenomena into interactive experiences remains an area of great potential for further exploration.

Given this context, this paper presents Einstein's Delivery, a DEG designed to support the teaching and learning of Special Relativity concepts. The game adopts a simplified contextualized narrative in which the player assumes the role of Albert Einstein, a bicycle delivery person navigating a city where the speed of light (c) is drastically reduced to a human-scale velocity. Developed as a 2D platformer, the game requires players to manage time distortions caused by relativistic motion to meet delivery deadlines. By integrating concepts such as time dilation and the Doppler effect directly into the mechanics, the proposal aims to translate abstract physics into an interactive, meaningful learning experience.

More than a proof-of-concept, this work investigates the efficacy of DEG as a medium for promoting scientific literacy and supporting conceptual understanding in physics education. Specifically, this paper provides two primary contributions:

- It describes the design and development of a digital educational game that maps core concepts of Special Relativity into gameplay mechanics within a familiar narrative context;
- It analyzes the challenges of using DEGs for physics education through a heuristic evaluation, highlighting key issues related to usability and pedagogical alignment.

The remainder of this work is organized as follows. Section 2 presents the theoretical background on Special Relativity and Digital Educational Games and discusses some related work. Section 3 describes the research methodology adopted, while Section 4 details Einstein's Delivery DEG, including its overview, mechanics, and educational elements. Section 5 describes the heuristic evaluation process, followed by a discussion of the results. Section 6 describes the threats to validity, and Section 7 concludes the paper and outlines future work.

2. Fundamentals and Related Works

This section presents the theoretical foundations supporting this work, focusing on Digital Educational Games and their role in Physics Education, as well as key aspects of learning Special Relativity.

2.1. Digital Educational Games

Digital Educational Games (DEGs) are interactive systems designed to support learning by integrating pedagogical objectives with engaging gameplay mechanics [Prensky 2003, De Freitas 2006]. Within the context of Game-Based Learning (GBL), these systems have been widely explored as tools to promote motivation, engagement, and active learning processes [Li et al. 2024].

From an educational perspective, DEGs enable experiential and exploratory learning, allowing students to actively interact with concepts rather than only observe them [Kolb 2014]. This is particularly relevant in domains that require conceptual understanding, as learners benefit from manipulating representations and receiving immediate feedback.

However, the effectiveness of DEGs depends strongly on the balance between pedagogical goals and gameplay design [Yu et al. 2021]. A common pitfall in educational game development is prioritizing pedagogical content to the detriment of playability, often resulting in experiences that resemble 'digital exercises' rather than meaningful learning environments, particularly when learning content is not intrinsically integrated into gameplay mechanics" [Habgood e Ainsworth 2011]. To address this challenge, frameworks such as *PlayEduc* emphasize integrating psychological, pedagogical, and design dimensions into game development [Aires e Madeira 2020].

In the context of Physics Education, DEGs are particularly relevant for subjects that involve high levels of abstraction. These tools allow the creation of simulated environments in which physical phenomena can be explored interactively. By embedding scientific concepts into gameplay mechanics, DEGs can support the development of intuitive and conceptual understanding through interaction and discovery [Boffi et al. 2024].

2.2. Special Relativity

The Theory of Special Relativity, formulated by Albert Einstein in 1905, represents a fundamental shift in our understanding of space and time [Alstein et al. 2021]. However, it remains one of the most conceptually demanding topics in physics education due to its counterintuitive nature, which often contradicts classical Newtonian intuition. The primary pedagogical challenge arises from the fact that relativistic effects such as time dilation, length contraction, and the Doppler effect only become significant at velocities approaching the speed of light ($c \approx 3 \times 10^8$ m/s) [Blumetti et al. 2025].

Because these phenomena occur at scales far beyond human sensory experience, students often struggle to reconcile abstract mathematical derivations with physical reality, limiting their conceptual understanding. Traditional teaching methods frequently rely on thought experiments (*Gedankenexperiment*) or equations, which may not be accessible to high school and graduate students, hindering an intuitive grasp of how reality behaves under extreme conditions [Blumetti et al. 2025].

In this context, Digital Educational Games offer a promising approach by enabling the creation of simulated environments in which physical constants can be manipulated. By reducing the speed of light to a human-scale value within a virtual environment, learners can visualize and interact with relativistic effects. Such environments transform abstract concepts into interactive experiences, supporting the construction of more robust mental models of relativistic physics.

2.3. Related Work

Recent research has explored the use of digital games and interactive environments to support the learning of complex scientific concepts, particularly in Physics Education. Educational games that integrate learning objectives with gameplay mechanics have shown positive results in promoting conceptual understanding. For example, intrinsically integrated games have demonstrated improvements in student learning by aligning mechanics and content in physics education contexts [van der Linden et al. 2024]. Similarly, serious games have been used as active learning strategies in physics instruction, promoting engagement and participation while supporting understanding of scientific concepts [Pacheco 2024]. These approaches emphasize interaction and experimentation, allowing learners to explore variables and observe their effects in real time.

More recent studies have also investigated immersive technologies, such as virtual reality, as tools for physics education. These environments enable learners to experience physical phenomena in ways not possible in traditional classrooms, thereby increasing engagement and improving conceptual understanding [Battipede et al. 2024]. In addition, game-based approaches have been explored for teaching modern physics concepts through narrative-driven experiences. Such approaches aim to contextualize abstract concepts, making them more accessible and meaningful to learners [Souza et al. 2024].

Despite these advances, many existing solutions focus primarily on visualization or simulation, with limited integration between core scientific concepts and gameplay mechanics. In several cases, the learning component is separated from the gameplay experience, reducing the potential for meaningful engagement and deeper conceptual understanding.

Furthermore, while there are initiatives addressing physics learning through games, relatively few works explicitly map principles of Special Relativity, such as time dilation and the Doppler effect, into mechanics that directly influence player decision-making during gameplay. In contrast, this work proposes a Digital Educational Game in which relativistic effects are not only represented but also actively shape the gameplay experience. By integrating these concepts into core mechanics, the proposed approach aims to support experiential learning and foster deeper conceptual understanding of Special Relativity.

3. Methods

This work is characterized as applied research with a qualitative approach, focusing on the design and preliminary evaluation of a DEG. The methodology was structured into three main stages (Figure 1): Concepts, Game Development, and Evaluation.

3.1. Concepts

To ensure that the game functioned as a coherent simulation, the initial phase of the project investigated which principles of Special Relativity could be translated into a 2D platform game. The scope was defined by variables players could perceive through movement and timing. This selection became the basis for two major developments:

- **A Physics Engine:** variables such as velocity, acceleration, and the Lorentz factor (γ) were put into the engine's core logic, creating a "low c"world where

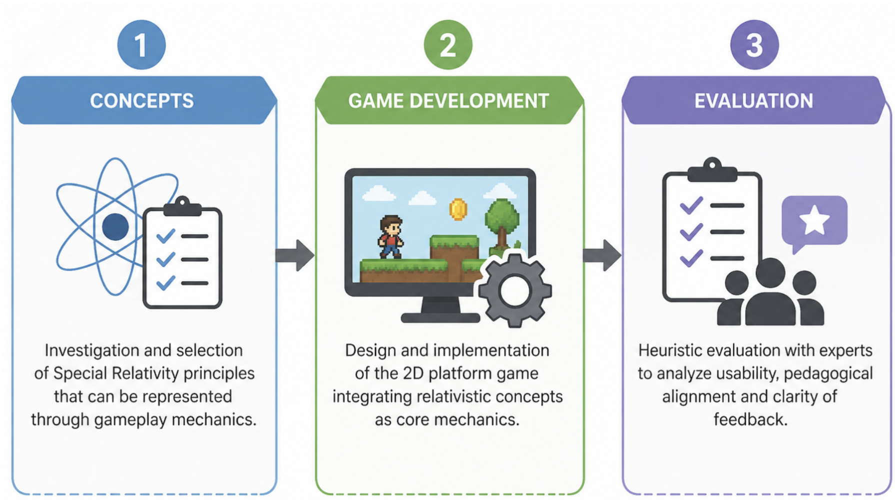


Figura 1. Overview of the methodology.

the reduced speed of light is consistent with the physical laws, dictating how the player interacts with the environment in real time;

- **Mechanic Driven Education:** This conceptual groundwork allowed us to transform the Doppler effect and time dilation from abstract phenomena into gameplay mechanics. The study provided the mathematical basis for calculating Own Time versus Client Time. By requiring players to navigate these differences, the game makes the relativity of simultaneity an intuitive experience. The study also allowed for the use of the Doppler effect as a gameplay constraint; at high speeds, the intensity of the color distortions can obscure environmental details, forcing the player to weigh the advantages of time dilation against the limitations of reduced visibility, while also providing qualitative visual feedback.

Ultimately, this phase successfully bridged the gap between complex equations and interactive play, ensuring that every mechanic is anchored in the theory of special relativity.

3.2. Game Development

Einstein's Delivery is a web-based DEG designed to teach the fundamentals of Special Relativity to high school and early graduate students. It consolidates these concepts through a playful world where the speed of light is drastically reduced, allowing players to directly observe relativistic effects. In the 2D platformer, the player, a bicycle delivery person, navigates urban obstacles like puddles and low branches while managing temporal and spatial distortions caused by their velocity.

Built with GameMaker for its support for 2D platforming and its relative ease of use, the central innovation is a Relativity Engine that computes the Lorentz factor (γ) in real time from the player's speed (v) relative to the game's reduced speed of light (c). This engine dynamically drives an Own Time clock and shader-based Doppler visual distortions. The pixel art style provides a familiar, accessible aesthetic, while the narrative casts Albert Einstein delivering pizzas to historically significant scientists, humanizing the subject, grounding physics in everyday life, placing it in historical context, and giving a clear objective: balancing speed to meet a deadline. The current version is a functional prototype and proof of concept, offering a stable environment for testing relativistic math in interactive gameplay.

3.3. Evaluation

The viability of Einstein's Delivery as a pedagogical tool was assessed through a formal heuristic evaluation utilizing the AHJED (Heuristic Evaluation of Educational Games) framework [Azevêdo et al. 2018]. This specific instrument was selected because it balances traditional usability metrics with educational effectiveness, which is critical for verifying if the game's ludic world successfully translates to conceptual learning. The primary goal was to determine if the interactive mechanics, specifically time dilation and the Doppler effect, were intuitive and pedagogically sound for students of modern physics.

The study involved four specialists with expertise in Educational Technology and Physics. Before engaging with the prototype, each participant reviewed and signed an Informed Consent Form (ICF)[1]. To ensure a standardized examination of the game's core mechanics, each evaluator was provided with a standardized form. The evaluators interacted with the game through free exploration.

4. Einstein's Delivery: A special relativity game!

In Einstein's Delivery, the player assumes the role of Albert Einstein as a bicycle delivery person, responsible for delivering pizzas within a strict time frame to scientists who were instrumental in the development of the theory of relativity. The primary challenge lies in the "low c"setting of the game world, where the player's pedaling speed can reach significant fractions of the speed of light. This allows the player to experience relativistic effects firsthand.

To complete a delivery, the player must balance their velocity. Moving at high speeds triggers time dilation and the Doppler effect, which are core game elements. By accelerating toward c, the player's internal clock slows down relative to the scientist's clock at the destination, effectively giving them more subjective time to navigate the challenges. However, high speeds also increase the difficulty of avoiding obstacles and trigger the Doppler effect, which can affect the player's vision. The DEG features two physical hazards: water puddles and low-hanging tree branches, which cause a sudden drop in velocity and a loss of temporal advantage (requiring the player to jump and duck). The core gameplay revolves around managing the Lorentz factor to maximize efficiency without increasing the game's difficulty to a point where the player can't avoid obstacles.

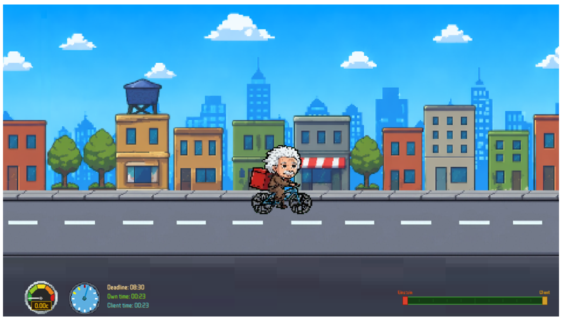
The game interface provides real-time feedback on relativistic variables, divided into four main components, as presented in Figure 2a and described below. The Doppler Effect distortion is shown in Figure 2b:

- **Scenario:** A side-scrolling urban environment where the delivery takes place. It contains the physical obstacles (puddles and branches). As the player accelerates, the scenario may undergo visual distortions, such as the Doppler Effect, shifting colors of the environment (the screen turns violet towards the direction the player is moving, and red away from the player's movement);

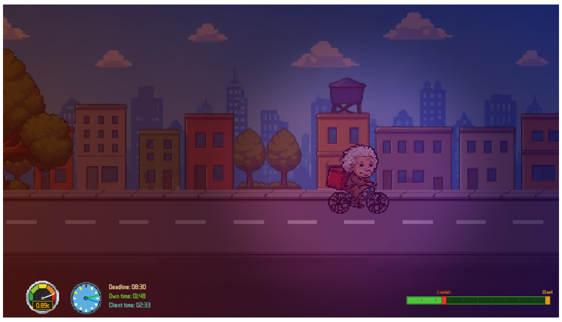
[1] Available at: `https://tinyurl.com/2m9euhyv`

- **Relativistic Speedometer:** A HUD element that displays the player's current speed as a fraction of the speed of light ($0.00c$ to $0.99c$). This helps the player understand the threshold at which relativistic effects become dominant;
- **Temporal HUD:** This component displays two distinct clocks. The Client Time represents the stationary frame of reference (the delivery deadline), while the Own Time shows the time passing for Einstein on the bicycle. This dual timer system is the primary pedagogical tool for demonstrating time dilation;
- **Status Bar:** A progress tracker showing the remaining distance to the delivery point.

At the end of each delivery, the system evaluates the player's performance based on Client Time and rewards them with stars in each phase (Figure 2c).



(a) Phase interface.



(b) Doppler distortion.

(c) Results interface.

Figura 2. Game interface and relativistic effects.

5. Results and Discussions

The evaluation of Einstein's Delivery focused on identify usability issues, pedagogical aspects, and the suitability of the educational design. The findings are categorized into the actual evaluation process and the synthesis of qualitative feedback.

5.1. Evaluation

The heuristic evaluation revealed a set of relevant issues regarding gameplay, educational elements, and the representation of relativistic physics in educational content. Table 1 summarizes the identified problems, focusing on those classified with a severity of major problem (3) to catastrophic (4). The discussion that follows focuses on the critical findings and their implications for both the player's gameplay experience and the pedagogical

Tabela 1. Identified usability problems from heuristic evaluation.

ID	Sev.	Problem Description	Possible Solution	%
GP5	3	Challenges frustrate the players.	Refine the mechanics involving collisions with puddles at high velocity.	25%
EE5	3	Players can select their preferred difficulty level.	Add more phases and segment them into different levels.	25%
EE6	4	The game features dynamic adaptability, tailoring gameplay to each player's specific skill set.	Include a quiz and segment the levels.	25%
EE7	4	No instructor customization.	Allow creation and customization of challenges.	50%
EC1	3	Educational content is seamlessly aligned with game elements.	Include a quiz to improve the reward system.	25%
EC2	3	Documentation provide clear explanations for all educational topics covered.	Include a content documentation section.	50%
EC5	3	Educational content is modularized into distinct topics.	Add more phases and segment them into different levels.	40%

GP: gameplay; EE: educational elements; EC: educational content.

clarity of the relativistic concepts, alongside proposed solutions to be implemented in future iterations of the prototype.

The heuristic evaluation of Einstein's Delivery revealed that while the core relativistic simulation is technically sound, there are significant opportunities to enhance its pedagogical flexibility and user experience. One of the most critical issues concerns the lack of instructor customization and game adaptivity (**EE7**) and **EE6**), both with severity level 4). Half of the evaluators (50%) highlighted that the game currently lacks a mechanism for instructors to create or tailor challenges to specific classroom needs (**EE7**). Furthermore, although the Relativity Engine accurately simulates physics, the game does not yet dynamically adapt its difficulty or content based on the player's specific skill set or prior knowledge (**EE6**). As noted by the participants, implementing a progressive system with segmented levels and a quiz-based diagnostic would better accommodate different learning curves. This is reinforced by the absence of a manual difficulty selection (**EE5**), severity level 3), which 25% of evaluators identified as a barrier to accessibility.

The structure and presentation of educational content also emerged as a primary area for refinement (**EC2 and EC5**). A significant portion of the evaluators (50%) noted the lack of integrated documentation that provides clear explanations of the simulated physics (**EC2**, severity level 3). While the gameplay is grounded in the Lorentz factor, the connection between action and theory remains somewhat implicit. As one evaluator suggested, including a dedicated documentation section would help "ground the phenomena more clearly."Additionally, **40%** of the participants indicated that the educational content should be more effectively modularized (**EC5**). Transitioning from a prototype with only three phases and a tutorial to a multi-phase structure would allow for the introduction of distinct topics in a more sequential manner. Although the educational content is currently aligned with the game elements (**EC1**), 25% of evaluators suggested that incorporating a quiz into the reward system would further solidify this connection.

Regarding gameplay mechanics and visual intuition (**GP5**), the evaluation identified friction between the high velocity simulation and the player's reaction time.

25% of participants flagged the current challenge level as potentially frustrating due to the movement logic obstacles. One participant noted that while the water puddles are an intuitive obstacle, at high speeds they "become impossible to dodge because they appear at the last second."This suggests that the mechanics of these objects need to be refined to ensure the difficulty remains engaging rather than frustrating. Similarly, the same participant observed that tree branches were initially mistaken for scenery rather than obstacles, indicating a need for clearer visual affordances.

Overall, the evaluation indicates that Einstein's Delivery provides a good foundation as a DEG. However, to fully realize its potential as an educational tool, the next phase of development should prioritize integrating a structured documentation system, greater instructor control over challenge parameters, and refining high-speed interactions to ensure an inclusive learning experience.

5.2. Synthesis of Qualitative Feedback

Qualitative comments from participants showed that the Relativity Engine successfully demonstrated the translation of the Lorentz factor (γ) into gameplay mechanics. By reducing c, the game transformed time dilation into a game's resource. Results from the heuristic evaluation show that the Temporal HUD (displaying Own Time vs. Client Time) was highly effective in making the relativity of simultaneity visible. However, a critical finding was the implicit nature of this connection. While the educational content is aligned with game elements ($EC1$), 50% of evaluators identified a lack of formal documentation within the game ($EC2$, severity 3). This suggests that while students may experience the effects of relativity through gameplay, they require in-game documentation to understand formal scientific terminology.

Participants emphasized that Einstein on a bicycle effectively humanizes the subject. The ludic world succeeds in removing the math-first barrier that often discourages students from engaging with modern physics. However, the transition from a prototype to an educational tool will require changing the phase structure to a modular one ($EC5$). By segmenting levels by difficulty and introducing new topics, the game can provide a more structured pedagogical progression. In conclusion, Einstein's Delivery proves that relativistic physics can be translated into a functional 2D educational game.

6. Threats to Validity

Despite efforts to ensure the rigor of this study, some threats to validity must be considered when interpreting the results [Yin 2009]. A threat to **construct validity** is related to the use of heuristic evaluation as the primary assessment method. This approach inherently involves subjectivity, as the identification of issues depends on the evaluators' interpretations of the game mechanics. Although a structured exploration guide was used to standardize the evaluation process, the results may still reflect the evaluators' professional backgrounds and perspectives.

Regarding **internal validity**, a potential threat lies in the calibration of the "low c" environment. The balance between maintaining relativistic accuracy and ensuring a playable experience is inherently subjective. Different evaluators may interpret the same design decision as either a necessary scientific simplification or a usability issue, which may affect the consistency of the findings. A limitation to **external validity** concerns the profile of the evaluators. The specialists involved in the study do not fully represent the target audience of high school and early undergraduate students. Their prior knowledge of physics and familiarity with digital games may have influenced their understanding of the mechanics, limiting the generalizability of the results to real classroom contexts.

Finally, **conclusion validity** is limited by the exploratory nature of this research. The data collected is predominantly qualitative and based on a small number of evaluators. Therefore, the findings should be interpreted as preliminary insights aimed at guiding the iterative development of the prototype, rather than as definitive evidence of its educational effectiveness. Further studies involving quantitative methods and larger samples are required to strengthen the conclusions.

7. Conclusion and Future Work

Einstein's Delivery demonstrates that Special Relativity can be effectively gamified by transforming the speed of light into a manageable gameplay variable. This research shows that the "low c"ludic world successfully bridges the gap between abstract equations and interactive experience. While the core physics engine is technically sound, the evaluation highlights that the transition from a proof of concept to a classroom-ready tool requires deeper pedagogical integration and more refined player feedback.

To address these findings, future development will focus on improving pedagogical transparency, gameplay mechanics, and adaptability. In particular, the implementation of a Relativistic Reference Manual is planned to explicitly connect gameplay phenomena, such as the Doppler effect, to their underlying mathematical principles, ensuring that learning is not only intuitive but also conceptually grounded. In addition, refinements to gameplay mechanics will be necessary to reduce the frustration identified at high velocities. This includes improving obstacle behavior, adjusting collision consequences, such as the impact of low-hanging branches on performance, and requiring more precise player actions, such as timed jumps and ducks, to maintain velocity advantages.

Furthermore, the introduction of adaptive elements should enhance the educational potential of the game. A quiz-based system is planned to strengthen the reward structure and support learning assessment, while also allowing teachers to customize content according to their curricular needs.

Finally, future work will involve a large-scale field study with the target audience. By deploying Einstein's Delivery in real classroom settings and applying pre- and post-test evaluations, it will be possible to more rigorously assess its impact on scientific literacy, engagement, motivation, and the learning of Einsteinian physics.

Use of Artificial Intelligence

Generative Artificial Intelligence tools were used only for language review and minor editorial support. Gemini was used for text refinement, and Grammarly for minor proofreading. All methodological decisions, analyses, and conclusions remain the sole responsibility of the authors.

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