The Great Garbage Patch: The Bionauts' Challenge: An Educational Escape Room on Marine Plastic Pollution and on Possible Solutions

Fabio Chiarello[1,2], Roberta Angelini[1,3], David Becerril[1,4], Alessio Cimino[1,5], Claudia Ceccarelli[6], Fabio Di Pietrantonio[1,5], Claudia Fasolato[1,3], Daniela Fioretti[1,7], Sandra Iurescia[1,7], Sara Laureti[1,4], Barbara Ruzicka[1,3] and Luisa Bracci Laudiero[1,7]

[1]Rome Technopole, Rome, Italy
[2]CNR-IFN, Rome, Italy
[3]CNR-ISC Sede Sapienza, Rome, Italy
[4]CNR-ISM, Rome, Italy
[5]CNR-IMM, Rome, Italy
[6]CNR-ARTOV, Rome, Italy
[7]CNR-IFT, Rome, Italy

Fabio.chiarello@cnr.it roberta.angelini@cnr.it david.becerril@artov.ism.cnr.it
alessio.cimino@cnr.it claudia.ceccarelli@cnr.it fabio.dipietrantonio@cnr.it
claudia.fasolato@cnr.it daniela.fioretti@cnr.it sandra.iurescia@cnr.it
sara.laureti@cnr.it barbara.ruzicka@cnr.it luisa.braccilaudiero@cnr.it

Abstract: Marine plastic pollution is a critical environmental issue, with the Great Pacific Garbage Patch symbolizing its severity. To engage the public in understanding this crisis and exploring scientific solutions, we developed "The Great Garbage Patch: The Bionauts' Challenge", an educational escape room set in a biology lab aboard an oceanographic research vessel. Participants must solve challenges and puzzles to learn about marine pollution and the role of plastic-degrading bacteria in ocean cleanup. First presented at Maker Faire Rome 2024, the escape room attracted students, educators, and families. A tabletop version was later introduced to extend its reach at other events. Through gamified learning, participants explored the impact of plastic waste and the potential of biotechnology in mitigating pollution. This case study highlights the potential of educational escape rooms for informal science learning. While results were encouraging, they should be interpreted with caution due to methodological limitations such as self-selection and group-based evaluation. Still, the experience demonstrates how game-based learning can foster curiosity and deepen understanding of STEM subjects and environmental issues.

Keywords: Educational escape room, STEM education, Science communication, Marine pollution, Plastic-Degrading bacteria, Environmental awareness

1. Introduction

Escape rooms have emerged in recent years as powerful tools for active learning and public engagement in both formal and informal educational settings. Originally developed as recreational experiences, escape rooms have been adapted for educational purposes due to their ability to combine narrative immersion, collaborative problem solving, and time-constrained challenges, which foster motivation, critical thinking, and engagement (Veldkamp *et al.*, 2020). These features make them particularly well-suited for STEM education, where abstract or complex topics can be made more tangible and memorable through interactive, game-based learning (Borrego *et al.*, 2017; Fotaris and Mastoras, 2019). Educational escape rooms can improve knowledge retention, stimulate curiosity, and support the development of transversal skills such as communication and teamwork (Taraldsen *et al.*, 2022). Their flexibility also allows for contextualized learning, where content is embedded within real-world scenarios, thus enhancing relevance and learners' engagement. Moreover, escape rooms are increasingly being used in science communication and outreach initiatives to engage broader audiences — including families, students, and educators — by transforming complex scientific concepts into accessible and immersive experiences (Veldkamp, Knippels and van Joolingen, 2021). While the educational potential of escape rooms and game-based learning is well documented, it is also important to consider some critical perspectives. Challenges include the substantial resources required for design and implementation, potential superficial engagement if the narrative overtakes the educational content, and difficulties in assessing learning outcomes objectively. Moreover, game-based approaches may not equally suit all learners, and their effectiveness can vary depending on the alignment between game mechanics and pedagogical goals. Including such considerations helps to frame the method not as universally applicable, but as one that requires thoughtful adaptation to context and audience.

This study presents "The Great Garbage Patch: The Bionauts' Challenge", an educational escape room designed to promote STEM-based environmental awareness through a game-based narrative. The ideation and development were carried out by an interdisciplinary team of researchers with expertise in physics, chemistry, biology, and engineering. These diverse scientific competencies enriched the design process. They also ensured the scientific credibility of the educational content at every stage — from narrative construction to technical implementation. This collaborative approach made it possible to create an experience that is both educationally effective and scientifically sound. By examining its structure, implementation, and audience reception, we aim to contribute to the growing body of research on the pedagogical value of escape rooms in science communication.

2. Marine Plastic Pollution: Challenges, Emerging Solutions, and the Role of Public Awareness

Plastic pollution in the oceans represents a growing threat to marine ecosystems, biodiversity, and global food chains. An estimated 8 million metric tons of plastic waste enter the oceans annually, accumulating in large-scale convergence zones such as the Great Pacific Garbage Patch — an area between Hawaii and California where ocean currents trap floating debris (Jambeck *et al.*, 2015; Lebreton *et al.*, 2018). These garbage patches are made up mainly of microplastics and fragmented polymers, which are highly resistant to degradation and make cleanup efforts difficult.

Addressing this issue requires a combination of mitigation strategies, including reduction at the source, improvement of waste management systems, and the development of novel clean-up technologies. Among emerging solutions, the use of plastic-degrading microorganisms has attracted increasing scientific interest. Certain bacterial strains, such as Ideonella sakaiensis, can degrade and consume polyethylene terephthalate (PET), a plastic material that was previously considered non-biodegradable, offering promising biological solution to plastic pollution in marine environments (Yoshida *et al.*, 2016; Danso, Chow and Streit, 2019). However, these approaches are still in experimental stages and require further research to assess their ecological safety and effectiveness on a large scale.

Given the complexity of marine plastic pollution and the multidisciplinary nature of potential interventions, public understanding and awareness are essential. Effective science communication plays a critical role in bridging the gap between research and societal action, fostering informed decision-making, environmental responsibility, and behavioral change (Moser, 2010; Stoknes, 2015; Di Paolo *et al.*, 2024). Engaging educational tools, such as science-based games and immersive experiences, have the potential to make these challenges more relatable and actionable for diverse audiences.

3. Case Study: "The Great Garbage Patch: The Bionauts' Challenge"

To explore the communicative potential of educational escape rooms in the context of marine plastic pollution and biotechnology, we developed *The Great Garbage Patch: The Bionauts' Challenge*, an immersive, STEM-focused experience presented at Maker Faire Rome 2024 — a major European event for innovation and science outreach, which attracted approximately 45 000 visitors. The escape room was installed in a closed 16 m² space, designed to replicate a biology laboratory aboard a fictional oceanographic research vessel. The setting included authentic scientific instruments and custom-made visual materials such as posters, diagrams, and experimental data sheets.

Figure 1: Pictures of the escape room

Participants entered in small groups and were guided by a narrative scenario: a severe storm is approaching, and a team of scientists (the players) has only 20 minutes to retrieve crucial data, kept in the ship's laboratory protocols, describing the optimal conditions to allow the growth and viability of marine bacteria able to degrade harmful plastics. These bacteria might hold the key to ocean cleanup, but the conditions for their optimal activity must be verified before the lab is evacuated. Players had to solve a series of interconnected puzzles and scientific challenges embedded in the laboratory setting, requiring them to explore real instruments and interpret scientific information presented on posters. Clues were distributed spatially and semantically across the room, promoting inquiry-based learning and observational reasoning (Veldkamp *et al.*, 2020).

A key element of the experience was a dedicated computer interface, a large 55" monitor with a mouse controller, that served both as a narrative device and an interactive learning platform. By discovering and inputting specific codes, participants unlocked short video clips containing scientific explanations and hints, progressively unveiling the underlying biological principles and the environmental significance of the mission. This hybrid design, combining physical exploration with digital media, aligns with established best practices in immersive science education, which emphasize multisensory engagement and authentic context as drivers of conceptual understanding (Taraldsen *et al.*, 2022).

The structure of the escape room experience is outlined below. After a short introductory briefing, participants are provided with a data sheet containing essential information, such as the biological cell incubator working temperature (38°C), the name of a bacterial strain, and the indication of a type of plastic, along with other experimental information, not useful for the game but contributing to the scientific setting. A handwritten note asks players to enter the start code "AUG" into the lab computer as they begin the escape room. AUG is the starting codon of the messenger RNA (mRNA) coding for Ideonella sakaiensis enzymatic protein responsible for PET degradation. Below, we outline the key sequential steps of the activity:

1. Upon inputting the sequence "AUG" on the lab computer, a video is launched that introduces the environmental context and prompts players to determine the correct incubation temperature, initiating the countdown.
2. Temperature Clue: A second sheet, found on the table, displays a different temperature (30°C). Inputting this value on the computer reveals a clue: "Between yellow and blue, length is the key", referencing the visible light spectrum.
3. Light Spectrum Analysis: A nearby poster shows the light spectrum, indicating that green lies between yellow and blue, with a wavelength of 549 nm. This numerical value is used to open a locked box.
4. UV Light: Inside the box, participants find a UV torch and a note suggesting that fluorescence will reveal the next clue in a poster. The message also provides the first RNA triplet: UCU.
5. Fluorescent Tubes: Participants use the UV torch to examine test tubes labeled with numbers. Only three tubes contain a fluorescent solution (labeled 0, 1, 4), pointing to poster numbered 014.
6. Hidden Message Reveal: Using the UV light, players uncover a hidden message on poster 014. It refers to bacterial degradation experiments in the incubator and includes the second RNA triplet: AGA.
7. Bacteria-Plastic Matching: In the incubator, Petri dishes show different bacteria acting on various plastics. Only one Petri dish contains biodegraded plastic. Matching this Petri dish with labeled one containing similar plastic on a nearby table yields a four-digit code: 0637.
8. Base Extraction Puzzle: The code unlocks a second large case containing beakers filled with various granular materials. Within the beakers, participants find capsules labeled with the four RNA bases (A, U, C, and G). Based on the previous clues, the participants must consider the differing grain sizes of the materials to deduce the final RNA triplet: UGC.
9. Code Assembly: Entering the complete sequence UCU AGA UGC (a segment of the mRNA of Ideonella sakaiensis) into the computer concludes the game and triggers a final video that summarizes the narrative and congratulates participants for successfully completing the mission.

4. Impact Assessment

During the three days of activity, a total of 450 individuals participated in the escape room experience. Following the activity, participants were invited to complete an optional anonymous questionnaire aimed at evaluating their engagement and perception of the experience. The questionnaire was filled out once per group, rather than individually, to capture a collective perspective on the activity. A total of 30 questionnaires were collected, corresponding to 162 participants. These results are indicative and should be interpreted with caution, due to self-selection bias and the group-based response format. These methodological choices were

primarily influenced by the context of the event — a large public fair characterized by high visitor turnover and limited time for extended interaction. In addition to the questionnaire data, qualitative evaluation was conducted through direct observation of participants' behavior during the escape room and informal interactions with them before and after the experience. In fact, at least one researcher with expertise in the field was always available to engage with participants in discussions about the scientific topics covered, both prior to and following the activity.

Participant groups ranged in size from 3 to 12 individuals (mean: 5.4), with a quite balanced gender distribution (approximately 45% women). The age of participants spanned from 5 to 63 years, with a predominance of students (middle school, high school, and university level) and families with children. All these groups successfully completed the activity within the allotted time, which was deemed sufficient (average rating: 4.9/5 on a Likert scale). Puzzle difficulty was rated as adequate (3.1/5), while the narrative scenario was considered realistic and effective (4.1/5). Overall enjoyment was rated very highly (4.7/5), and the perceived educational value of the experience was also strong (4.3/5). Informal interactions supported these findings, revealing widespread appreciation for the activity, increased interest and curiosity regarding the scientific content, and a noticeable improvement in participants' ability to articulate key concepts — evidenced by comparative discussions held with researchers before and after the experience.

5. Conclusions

This case study illustrates the effectiveness of educational escape rooms as a tool for informal science education and public engagement. *The Great Garbage Patch: The Bionauts' Challenge* successfully merged scientific content with a compelling narrative structure, offering participants an active and immersive learning experience centred on marine plastic pollution and emerging biotechnological solutions. The observed learning outcomes, along with high engagement and positive feedback, suggest that game-based formats can foster cognitive and emotional connections to complex environmental issues. Despite the limitations inherent in the evaluation methods — particularly the voluntary and group-based nature of feedback collection — the experience yielded valuable insights into audience reception and educational impact. The active presence of field experts and the integration of real scientific instruments further enriched the activity, enabling participants to relate abstract concepts to tangible experiences. Overall, this initiative supports the growing body of evidence advocating for the integration of gamified learning approaches into science communication strategies aimed at diverse, non-specialist audiences. Future iterations may benefit from enhanced evaluation frameworks and expanded dissemination to broader educational contexts.

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