Design of a Serious Game for Children to Raise Awareness on Plastic Pollution and Promoting Pro-Environmental Behaviors

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The massive presence of plastic in the oceans, both in the form of large debris and micro-plastic, is raising global concern due to its severe effects on the marine environment and fauna, causing loss of biodiversity and potentially threatening human health. Even though this is due to poor waste management, the great production and consumption of single-use plastic is a significant exacerbating factor. Despite policies and bans can be effective measures, there is also the need to raise consumers' awareness, so they can make more sustainable choices when purchasing, using, and dismissing products. In particular, educating young citizens and encouraging them to engage in pro-environmental behaviors is a fundamental task to reach this goal. In this work, we present Contact from the future*, a digital game on plastic pollution for children, to create awareness and stimulate pro-environmental behaviors, discussing the definition of objectives and requirements, as well as the design and development of the application.*
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Introduction

The presence and persistence of plastic waste in natural surroundings is one of the main environmental concerns at the moment: plastic pollution can be found in many forms and implies a series of relevant consequences on marine ecosystems, fauna, and vegetation. Large plastic debris represents a serious hazard for many animals, dying suffocated or trapped by plastic bags, nets, and other objects [1]. Moreover, micro-plastic is easily ingested, intoxicating fishes and shellfishes that are then traded on the food market. Therefore, it is also a threat for consumers' health [2]. A main problem due to the presence of plastic in water is that it is lethal for turtles, that play a major role in maintaining healthy seagrass beds and coral reefs [3], impacting on both sea and land ecosystems, as seagrass is also a soil fertilizer [4].

The extent of this damage is severe: according to Lebreton et al. [5] between 1.15 and 2.41 million tonnes of plastic waste enters the ocean each year from rivers due to poor waste management at many levels. This includes fishing and industrial activities, but also littering on beaches and other locations, from which plastic objects are moved through atmospheric transport.

Most of the plastic production is due to packaging, which represents 58% of the plastic waste as reported by the European Commission [6]. For this reason, governments and institutions are taking a variety of measures, limiting and banning single-use plastic, such as plastic bags, bottles, and cups [7]. Nevertheless, plastic demand in Europe continues to grow and only the 6% of the produced plastic is composed by recycled one [6]: despite the increasing efforts taken out by the EU, the current plastic market is not based on a circular economy.

Since coercive measures are not sufficient to face the challenge of reducing and improve the management of plastic waste, many institutions are also focusing on persuasive interventions: for instance, promoting and sometimes distributing reusable items, such as bottles. In fact, behavioral policies have been recognized as fundamental to achieve sustainability goals set by the EU, including pollution and biodiversity loss caused by plastic waste [8]. In particular, consumer behavior plays a fundamental role, therefore it is essential to engage people in choices and practices related to products durability, reuse, and repairability [9]. Reaching this objective is not trivial, since despite environmental concern is diffused among the population, it does not automatically lead to sustainable behaviors, as it can be hard to relate personal habits and large-scale issues such as climate change [8]. Hence, it is necessary to educate people to be conscious consumers, not only raising awareness but also providing them the knowledge and tools to take more pro-environmental actions. In particular, it is fundamental to intervene with children and teenagers to raise responsible future citizens, supporting them in the formation of pro-environmental attitudes. Educating the next generations plays a fundamental role in the transition toward more sustainable societies: it has been acknowledged by many researchers that this has a higher impact and return compared with interventions taken out later in life [10]. In fact, the advantage of targeting younger age groups is

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Table 1 Different case studies categorized according to typology and aim

Case study	Typology	Aim		
		Awareness	Information	Instruction
Ahn et al. [22]	VR experience	•		
Thomas et al. [23]	VR game	•		
Nicoll et al. [24]	Simulation (various)	•		
Rossano et al. [27]	2D game	•		
Fox et al. [25]	PC game	•	•	
D'Angelo et al. [26]	Tabletop game	•	•	
Souza et al. [28]	PC game		•	
Fernando et al. [29]	2D game			•
Nunes et al. [30]	Mobile game			•
Lee and Kim [31]	Mobile game			•
Castellano et al. [32]	Social robot/tablet game			•
Speth et al. [33]	2D game	•	•	•

Note: Symbols indicate the aim of each case study.

that they still have to develop several habits that are well established in adults, including the purchase and consumption of plastic products.

To this regard, a promising tool is one of the educational games: a survey of these applications in the field of sustainable development is presented by Katsaliaki and Mustafee [11]. They found games to be able to increase understanding of environmental issues and sustainability strategies. Given their engaging and rewarding nature, digital games and edutainment can also be effective as learning means for children and adolescents [12,13].

In this work, we present a digital game on plastic pollution for children to be played when visiting an aquarium or marine-related exposition, with the aim of creating awareness about the problem and stimulating pro-environmental behaviors, raising future conscious consumers. We discuss the definition of objective, requirements, as well as the prototyping and future development of the application.

Fig. 1 Alex, the character of the game in his room

Digital Games and Experiences on Related Environmental Issues

Serious games and simulations are a widespread and effective tool for science education [14] and to create awareness of sustainability related-issues [15,16]. Moreover, game-based learning has been acknowledged as a useful means to teach primary school children regarding several subjects, and also to achieve children's behavior change, for instance for health and wellbeing [12,17].

Specifically, many games and other digital or virtual experiences presented in literature treat a wide range of topics related to plastic pollution and to the environmental damages caused to the marine ecosystem by human activities. Examples are mentioned by Ref. [18], who present a review of digital games for biodiversity conservation, and by Stanitsas et al. [19], that discuss games for sustainability transition. Here, we mention different works proposing games and other applications developed to depict how human activities can transform and harm the natural environment, highlight the behaviors that are responsible for it and teach the players about possible solutions. Moreover, we describe the different modalities, technologies, and media used to implement the games.

Virtual reality (VR) is a valid tool to create awareness of certain environmental issues [20,21]. VR allows users to explore areas of the planet that would not be accessible to them otherwise, as oceans, seabeds, and diving sites, overcoming not only a physical but also an emotional and psychological distance. In fact, Ahn et al. [22] propose an immersive experience that allows the player to embody an animal in the ocean, facing problems caused by the acidification of the marine environment, to create empathy and awareness. Thomas et al. [23] present a VR diving trip, where the beautiful environment is progressively spoiled by plastic trash that the player has to collect, reaching a point that is impossible to succeed. However, also nonimmersive experience can achieve a similar objective: *Infinite scuba* is an ocean simulation to connect people with nature and raise awareness on environmental issues and ecosystem conservation [24].

Similarly, Fox et al. [25] take players in a VR journey to a river contaminated by illegal waste and pollutants dumping, that needs to be cleaned up. In this case, participants are explicitly informed about the human activities causing the environmental conditions they face. D'Angelo et al. [26] aim at raising awareness on the risks of overfishing through a tabletop serious game to be played by visitors at a local aquarium. The goal of the game, called *Fishing with friends,* is to make money by fishing, but then players will confront the damages they caused to the ecosystem, highlighting the contrast between human activities and environmental conservation. The 2D serious game *SeAdventure* for primary school children informs the kids about the risk of some animal species extinction in the Mediterranean Sea due to the presence of litters [27]. The children control animals (white shark, turtle, hippocampus, and red tuna) and have to pay attention to eat fish and not trash, otherwise they lose life. The game is focused on providing information about the animals and habitat rather than on the presence of litters. Souza et al. [28] present *Save the ocean*, a 2D computer game in which players control cyber sharks that, on the contrary, have to eat trash from the ocean. The game also provides information about the different damages caused by each type of litter, requiring players to select them. In fact, differently from the previous case studies, the game aim is to highlight the harmfulness of specific items based on their time to degrade, rather than describing their effects on the marine ecosystem.

Fernando et al. [29] propose a *Trash Attack*, a serious game, developed with the aim to promote environmental awareness and correct waste segregation. The player takes the character of a heroine that has to clean the environment shooting at the waste

Table 2 Requirements considering the game aim and correspondent activities and objectives

Aim	Game activity	Objective
Awareness	Drawing	Reflection and empathy with a peer from the future
Information	Quizzes, puzzle	Including data and information on plastic pollution
Instruction	Matching game	Practicing solutions (recycling, reuse, consumption)
General	True-and-False game	Repeating concepts, reinforcement

with the correct gun, depending on if it is biodegradable, non-biodegradable, or recyclable. The mobile game *Protecting the earth* [30] also focuses on waste management, including topics such as recycling, reuse, and garbage reduction: the game is indeed divided in three stages, each one proposing different challenges to the player. *Trash treasure* [31] is another mobile game to teach kids about domestic waste classification, recycling, and reuse, also explaining the difference between combustible and incombustible waste and the concept of energization. Castellano et al. [32] use a social robot to compete with kids on litter recognition and sorting and educate them on waste disposal.

Differently from the previous examples, the 2D game *Eco Champion* [33] serves a series of purposes. In fact, it informs players on the harm and impact of human activities on the environment and engages them in providing possible solutions. The game is composed of a series of similar mini-games. An example is *Saviour of the Seas*: users are informed that nylon nets degrade the marine ecosystem, taking 400 years to completely disintegrate, harming animals in the meanwhile. Players have to try and fix the situation, also convincing fishermen to change their habits and use other kinds of nets.

What is the Aim? A Categorization

The mentioned works aim at providing one or more among three types of knowledge:

- Awareness: knowing the harm human activity can cause to the environment, ecosystems, animals, and society;
- Information: knowing the quality and entity of damages as related to specific human activities or actions;
- Instructions: knowing how to reduce the impact of certain activities or actions, or alternative ones.

Traditional campaigns can aim at creating awareness. An example is communicating data about animal extinction, describing how many animals die due to environmental issues. Another kind of campaign is focused on information, for instance, it can be against single-use plastic, illustrating the quantity of products and litters that we consume and ends up in the ocean. Finally, an example of instruction is suggesting purchasing reusable bottles and avoiding straws. The same criteria can be applied to the games we discussed, as shown in Table 1.

Among the reported games, only one has multiple aims, while most of them focus on one of the three aspects. Awareness can be a powerful tool to stimulate people to act pro-environmentally, however it is not sufficient, as there is often a gap between people's awareness and beliefs and their behavior [34]. Moreover, only experiencing a negative scenario can be frustrating for users, making them feel as they have no power in a catastrophic situation: this can cause people to assume defensive positions and even lead to disbelief [35]. Similarly, negative emotions and reactions can be linked in the users' brain with the topic proposed, generating an overall avoidance behavioral response [36].

Ahn et al. [22] highlight that in many cases, the most serious damage is, the least is perceived as a responsibility. Conversely, when they recognize their responsibility, they tend to minimize the problem. Furthermore, as pointed out by Nicholson-Cole [37] people usually feel that dealing with environmental problems should not be citizens' responsibility but should rather be managed via Government-led initiatives.

Hence, while informing people about the correlation between human activities and environmental issues is a step further, they must be linked also to individual actions. On the other hand, aiming at only instructing, explaining people which behavior to perform or avoid, we would exclude a powerful motivator. In fact, when people do not directly experience the effects of environmental damages, they do not feel the urgency of changing their daily actions [37]. Fear—in this case of environmental issues—and, more importantly, and ethically, hope—of conserving the natural ecosystem—are indeed powerful motivators, as described by Fogg [38].

Another distinction to discuss about is the kind of experience and supporting technology to use, including VR experiences, tabletops, mobile and PC games, and the use of robots. VR immersive experiences can create awareness enhancing the connection with the natural environment, as it provides a feeling of "being there" defined as sense of presence [35]. Tabletops [26] allow interaction of groups of players, in a way that can be useful in public and educational contexts, robots can introduce a social interaction [32]. However, their availability of similar technologies is not high, also due to the high costs and need for proper spaces to be used.

In contrast, 2D games require PCs and mobile technologies such as smartphones and tablets that are very accessible but provide limited space and interaction. Hence, depending on the number of users to be reached, type of game, and context of use, the choice of the technology and experience to develop should be carefully evaluated.

Contact From the Future: A Digital Game on Plastic Pollution for Children

For the reasons discussed above, we decided to adopt a multi-objective approach with a game that includes the whole picture, linking environmental issues, information on their causes, and suggestions to change behavior within an emotionally engaging and positive (rather than frustrating) scenario.

The game was developed to be played in a context as an aquarium or exhibition on marine ecosystem conservation or plastic pollution and to involve 8–11 year-old visitors, raising their interest in environmental topics. We opted for a 2D game to be played on tablets to communicate with a remote avatar, displayed in the

Fig. 2 The drawing task performed by the player

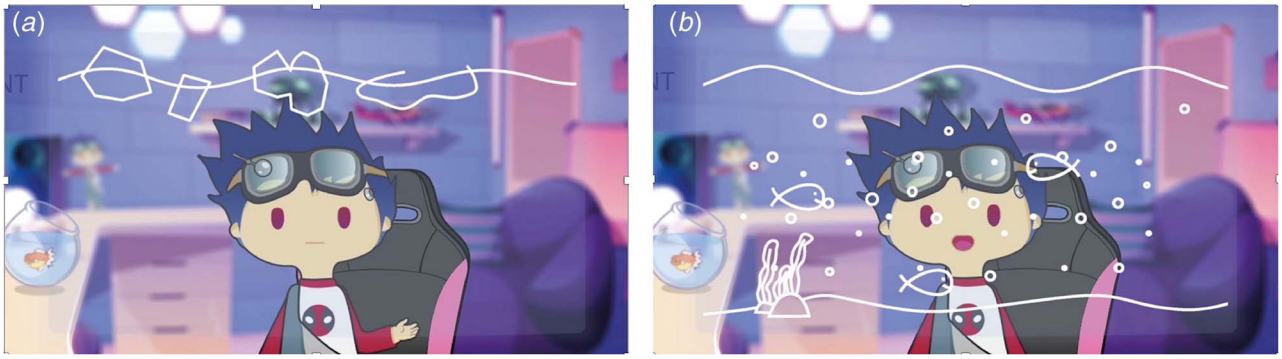


Fig. 3 Alex shows the player drawings representing the ocean full of plastic, then he shows how it imagined it to be when it was populated by fishes

aquarium spaces using projectors or screens, based on the need for highly available devices and on the organizations of the aquarium interiors.

The character interacting with the player is an 11 year-old boy, named Alex, who comes from a dystopian future and tries to communicate with the past (Fig. 1). On his present, the Earth is completely polluted, and the oceans are full of plastic waste, while many sea creatures have disappeared. He aims to understand what happened in the past and he wants to convince people to change their behavior to improve his present. To do this, he provides information and suggestions using quizzes and games for players to realize how important it is to change, and how to do it.

In the following part, we further describe the game requirements and how they were satisfied in the game design.

Requirements and Game Structure. We established the main requirements to answer the three aspects of the game aim previously defined. The game is composed of three activities, each one dedicated to one of the aims, setting different practical objectives as shown in Table 2.

Awareness is raised by the contact with Alex, who asks the player to draw how the ocean looks like (Fig. 2) and tells them that in his time, he has no chance to experience the marine environment the same way, as it is completely polluted. Information is achieved by asking players to answer quizzes (Fig. 3(*a*)), communicating data on plastic production, consumption, and its consequences. Alex asks questions to understand why people in the present consume plastic and to understand their level of awareness.

The quiz also allows to collect data about visitors' knowledge on the topic, questions include

- Approximated amount of plastic produced globally;
- Opinion about if it is necessary;
- What they think that typically happens to plastic;
- What they think that should happen to plastic;
- Approximated amount of plastic they think it enters the ocean;
- If they are worried about the situation;
- True or false answers.

Once players are aware of the damages caused by plastic in the long term, and of the human activities causing them, Alex proposes two games. One is a puzzle game (Fig. 4(*b*)) to identify where the plastic comes from: users have to recompose different plastic litters. The second game asks players to match problems and solutions, reflecting on recycling, reuse, or alternative products to plastic (Fig. 4(*c*)). Finally, some concepts are repeated, running a true-and-false game (Fig. 4(*d*)), as a reinforcement and in the end, a reward certificate for participating in the game is displayed.

Game Design and Features

Aesthetic: Character and Background. The use of a character to communicate with children is fundamental in many games; however, attractive characters can take different forms. Fernando et al. [29] are inspired by comic art, Nunes et al. [30] suggest that user friendly characters are fundamental to attract users to topics that are usually not interesting for them (as can be plastic pollution for children) and design a series of nonhuman avatars, focusing on their personality. Conversely, Nunes et al. [30] point out that similar demographic characteristics, including ethnicity, increase the possibility to identify with characters. The character in *Contact from the future*, Alex (Fig. 1), was designed as a child of the same age as the players, to help them sympathize—based also on the scientific observation that at that age, some empathic processes have already been developed [39,40]—with a peer that does not have the luck of enjoying nature as they can. The style of the character and environment around him recalls one of the Spanish Youtuber Auronplay, that is popular among the target age group.

Graphic Information Elements. The game contains video explanations representing how the ocean will look like at Alex's time. The graphics look like if Alex himself made them, using a linear hand-drawn style, elements are designed in a simple and recognizable way (as for the drawing in Fig. 3). The game includes also some simple 3D representation to show previsions of the quantity of plastic produced and disposed in the future, compared with the area of lake Maggiore in Italy.

Games Feedback and Score. In the different games, the score is assigned as shown in Fig. 5. Three kinds of feedback are provided:

- True or false answers feedback: The correct reply is displayed.
- Stickers feedback: During the matching game, users select the sticker corresponding to the solution for the object shown by Alex (e.g., Alex shows a plastic bottle and the user selects "reuse"). When the users send the sticker, if it is correct the given item disappears, while in the opposite case, the sticker returns back.
- Score feedback: When the users complete a task, the points that they earn appear and move to be added to the total score. The trophy, which is located on the top right corner of the screen and near the score, shakes while the points increase in the score.

Feedback from the answers and the stickers serve educational purposes, teaching users the proper information or answer to the problem. The score provides not only a feedback, but also a sense a reward, representing a motivational element and serving the purpose to keep the user engaged during the whole game [41].

In the puzzle game, points are assigned depending on the time: the shorter it takes for the player to complete the task, the more points he/she will get. In the matching game, the player will gain more points if the first guess is correct, then the score will diminish for every trial. In the quiz, correct answers will assign points to the player.

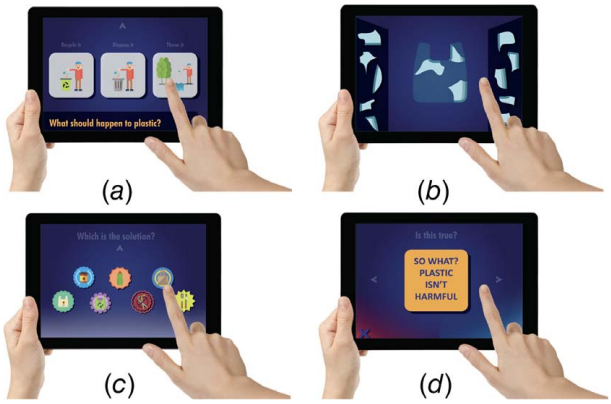


Fig. 4 (*a*) The quiz, (*b*) the puzzle game, (c) the solution match, and (*d*) the true-and-false game

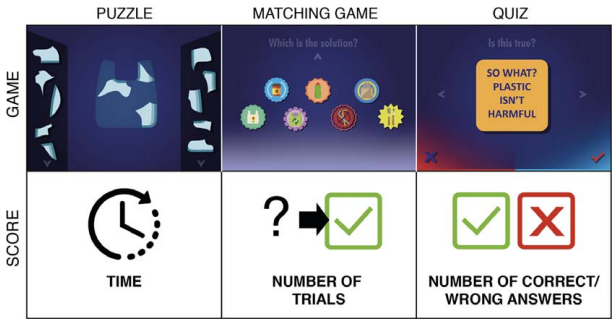


Fig. 5 Scoring system in the different games. Points are assigned depending on time (puzzle game): less time will give more points. Similarly, a minor number of trials (matching game) will assign a higher score. Finally, correct answers (quiz) will add points to the player's score.

Implementation and Interaction. The game was developed using Unity 3D,[2] a cross platform tool used to develop games, simulations, and applications for a variety of supports and operative systems.

The character and graphics were developed using Adobe Illustrator[3] and animated using Adobe Character Animator,[4] while the audio content was created through Audacity.[5]

The application is structured as a server client communication, the server side consists of the scene from the future, including Alex who is sitting in his room, displayed in the aquarium environment. The client scenario is accessed by players, standing in front of a screen or projected wall, using smartphones or tablets, answering the quizzes proposed by Alex and playing the games (Fig. 6).

The game interaction between the two parts happens in the form of a dialogue: asks questions to the payers and the user replies, using the device in their hand: according to the answer, there are different types of feedback, including visual features and sounds. The workflow of the application is shown in Fig. 7.

Data from the client, including provided players' general information (age group and group name), answers and scores are collected. The language used by Alex is English; however, the game also displays subtitles that are currently available in English, Italian, and Spanish.

A prototype was developed installing the application on a smartphone (LG k20, Android 7.0 Operating System) as clients and using a PC screen as server.

[2]http://www.unity3d.com
[3]https://www.adobe.com/it/products/illustrator.html
[4]https://www.adobe.com/it/products/character-animator.html
[5]https://www.audacityteam.org/

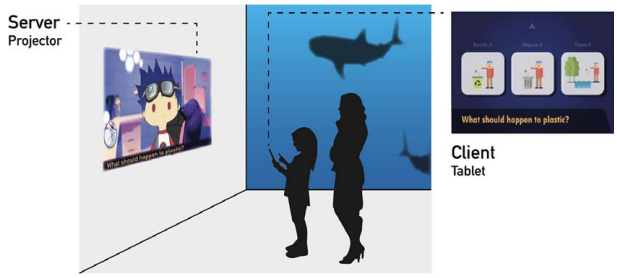


Fig. 6 Server client communication and interaction in an aquarium. The visitor, on the client side, can answer the question proposed by Alex, on the server side.

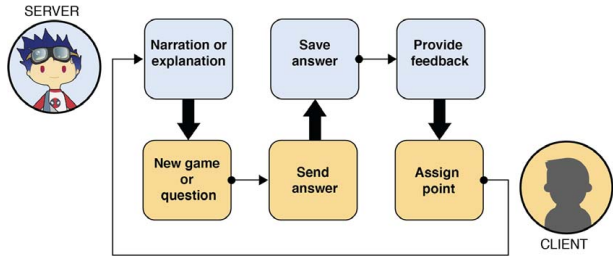


Fig. 7 Application workflow. The server starts with a narration followed by a game or question on the client, the client chooses an answer that is saved on the server. The server provides a feedback and, based on that, the clients assign points. Then the server continues providing explanation of the score, leading to a new question or game.

User Study 1. During its development, the prototype application has been tested multiple times by interaction design experts in the university to verify the functioning and the main usability aspects of the game. This allowed dealing with some criticalities related to the functioning and usability of the application, and including the gestures required for the interaction. The final version was tested by 15 users, both students with technical (engineering) and humanistic (psychology) backgrounds, observing participants during the use, asking questions and collecting feedbacks for future adjustments. The aim of this first test was to perform a qualitative assessment, in particular, the following aspects were evaluated: overall impression of the game, enjoyment of the UI and storyline, interaction design aspects, appreciation of the avatar. The users judged the game as interesting, enjoyable, funny, and satisfactory. As far as the UI is considered, the users evaluated the application as aesthetically appealing, although some of them highlighted that it could be improved somehow. The suggestions mostly regarded some elements in the interface (e.g., using colors as red and green for the true and false questions), to make it more understandable and immediate (also in accordance to the affordance value of the buttons), and the way some questions were set, that could be clarified. The storyline was found interesting, captivating, and informative by all the participants. In particular, the interaction with Alex and the conversation format, as well as the information provided were found adequate. However, opposing views were found as regard the duration (i.e., too long) and the intelligibility of the story (i.e., difficult to be followed). As regards to the interaction design, after an initial difficulty experienced in understanding how to interact with the system (that consists of both a Tablet and a PC), the application was evaluated as easy to be used. Moreover, the avatar overall aspect, received very positive feedback. In general, some participants found that further explanations about the reasons why each subgame is played would make the experience more effective. Finally, some suggestions went into the direction of suggesting some adjustments that could be implemented to improve the experience on smaller mobile devices. That is using smartphones instead of tablets could make the interaction more

Table 3 Users feedback on the application aesthetic, functionalities, and information provided

	Strongly agree	Agree	Nor agree/ nor disagree	Disagree	Strongly disagree
Attractiveness of the app					
Visually and aesthetically pleasant	71.4%	28.6%	–	–	–
Storyline was interesting and captivating	57.1%	42.9%	–	–	–
Efficiency of the app					
Easy to learn how to use it	28.6%	57.1%	14.3%	–	–
Flexible enough to interact with it	14.3%	71.4%	14.3%	–	–
Info of the game was clear and easy to follow	28.6%	42.8%	14.3%	–	14.3%
Awareness					
App motivated to learn more about plastic pollution and to finish the game	28.6%	42.8%	14.3%	–	14.3%
Storyline was informative	42.8%	42.8%	–	–	14.2%
Storyline was too long	28.6%	–	14.3%	42.8%	14.3%
Storyline was too difficult to understand	14.3%	42.8%	–	14.3%	28.6%
Storyline was easy to understand	28.6%	28.6%	28.6%	–	14.3%
Information					
Too much info in the app	28.6%	–	14.3%	42.8%	14.3%

Table 4 Users' feedback on the app experience

	Yes	No	It needs improvements	Visual info needs improvements	It was complicated to use	*I* was bored
Stimulation						
Was it fun to use the app?	42.9%	28.6%	28.6%	28.6%	42.9%	–

Table 5 Users' overall satisfaction

	Highly satisfying	Moderately satisfying	Not satisfying	Dull	Pleasant	Cluttered	Easy to learn
Satisfaction							
How would you rate your overall experience with the app?	42.9%	14.3%	–	–	57.1%	14.3%	71.4%

Table 6 Users' feedback on the avatar

	Creative and fun to interact with	Requires improvement	I'd prefer an avatar that looks like me	I'd prefer an avatar that is the same gender as me	I'd prefer to select an avatar that has facial features like mine	No changes to be made to the avatar
Avatar						
How would you rate the overall impression of interacting with the avatar used in the game?	57.1%	14.3%	–	–	14.3%	42.9%

complicated. With respect to the aim of the app, the users declared that the application increased their awareness about the problem and motivated them to learn more. However, someone reported that too much information was provided in the application and that it was cognitively draining.

User Study 2. A second test of the prototype application was performed aiming at a quantitative evaluation. The test was performed with seven users (four females, aged between 20 and 34). The test investigated the overall application considering aesthetic and functional aspects, information provided and users' engagement, overall satisfaction regarding the experience with the application and the avatar. Results are listed in Tables 3–6, and show some similarities with the first user study described in the User study 1 section. In this case, we did not use a Likert scale (like in User study 1) to allow participants to express different opinions. This would make the experience's assessment more detailed.

For questions in Table 3 users could select only one answer for each question, while for the others it was possible to select more answers. Considering Table 3, positive feedback was given regarding the application attractiveness, the overall efficiency was also mainly positive, while some users found the storyline too long and complex. Similarly, to the previous user study, some participants found the quantity of information to be slightly abundant. Moreover, most participants found the application fun to use, but also complex (Table 4). According to some participants it could be improved, in particular considering visual aspects. The overall satisfaction with the application prototype was good (Table 5). However, a small percentage of users defined the

experience as cluttered. The avatar was also appreciated by the participants (Table 6).

Discussion and Conclusion

We presented the design and development of a digital game for 8–11 year-old children on plastic pollution, one of the major environmental problems the world is facing, as both large litters and micro-plastic have a serious impact on the animals and vegetation of the oceans and, ultimately, on human health. The need for an urgent change in citizens' consumption habits makes it a priority to educate the next generations of consumers to make possible a consistent pro-environmental transition. The aim of the game is threefold: to generate awareness about the damages on marine ecosystems, to provide knowledge on how and to which extent human activities contribute to the phenomena, and finally, to promote behaviors that can help to diminish people's environmental impact. These objectives were set after considering the state of the art on games regarding similar topics, as well as principles of environmental education and the main scientifically based factors contributing to behavior change in humans.

The game is intended to be played when visiting an aquarium or exhibition, connecting mobile devices to a system communicating through a large screen or projector. However, one of the possible future developments of the application is related to provide additional contents and games to be played at home or elsewhere with the aim to continue the experience, consolidate the learning process, and increase the effectiveness of the intervention on actual people's behaviors (also by means of social interactions).

We developed a prototype, which was continuously monitored and finally tested with interaction design experts, cognitive psychologists, and students with different backgrounds. In particular, two user studies were performed. The trials produced positive feedback considering the game format, interaction with the character and content and information provided, as participants found the experience enjoyable, entertaining, and instructive. However, they also highlighted room for improvements to implement before conducting tests with the final users' group. These included aspects regarding the interface, interaction and instruction administered, and also some clarification on the questions asked and information provided. It is important to manage these criticalities since they might be even more challenging for children.

Another possible change to be implemented regards the graphics, as for a quick development of the game concept, we used a simple 2D environment. However, children of our target age group would potentially appreciate a different (and immersive) style as compared with the one shown in the prototype. Hence, the aesthetic is certainly one of the aspects to investigate in future steps, when target users will be involved.

After the implementation of these adjustments, the following step would then be to test the second prototype with children and proceed with further improvements and additions. Finally, the whole system should be implemented and tested in a specific setting (an aquarium or exhibition) and on a wider sample, collecting data and assessing the impact the game could have on the education of future citizens and consumers. In fact, both the presented studies were aimed at assessing the usability of the prototype. Investigating the potential people's reaction or behavior to the digital game will require a broader user sample.

A further step would be assessing a specific change of plastic consumption behavior among the application's users. A possibility is to perform questionnaires regarding plastic consumption behavior before and after the game experience. However, since users are young children, this would require adults' involvement (e.g., parents). Another option is testing children's behavior through a second game or simulation in a VR scenario, requiring players to engage in shopping or waste disposal tasks.

Conflict of Interest

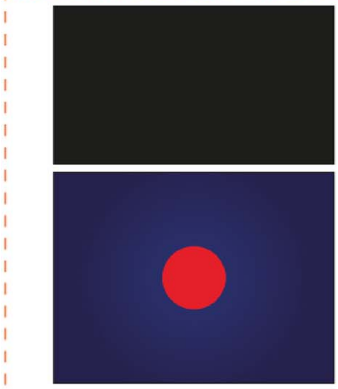
There are no conflicts of interest.

Data Availability Statement

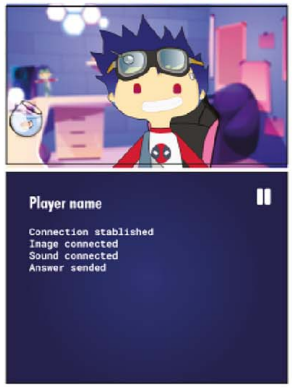
No data, models, or code were generated or used for this paper.

Appendix

The following storyboard represents the game steps, including some of the narrations, the different games, questions, and explanations.

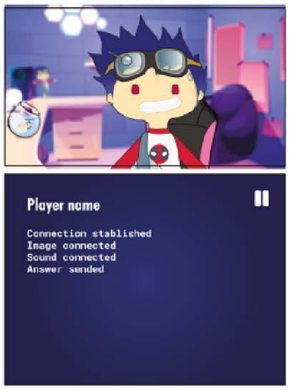


click on screen

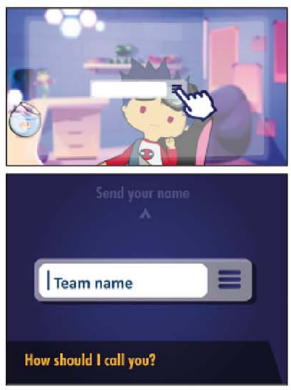


Hello? Hello? I got a signal!! … Does anyone hear me? Mmm.. Do you understand me? Do you speak my language?

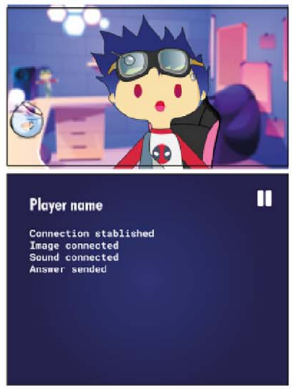
select language



Yes! Yes! I have a signal! Yeah!! I manage it! This is amazing!! Wow! Wait… Can you see me?? I'm Alex from 2062, who am I talking with?

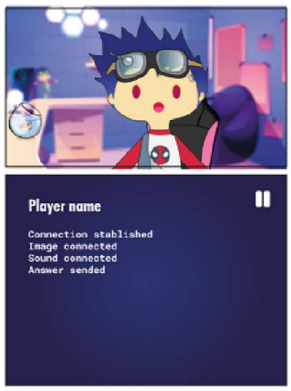


write

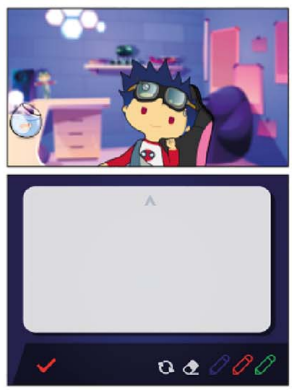


Yeah! I receive your message! I finally manage to communicate with the past! Where are you from?... And, how old are you?

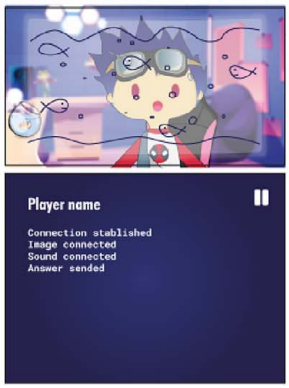
fulfill a profile



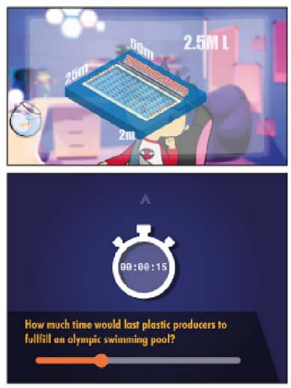
Really? So, you have seen the sea! Can you please show me how is it?



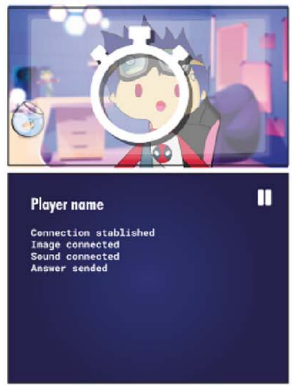
draw sea



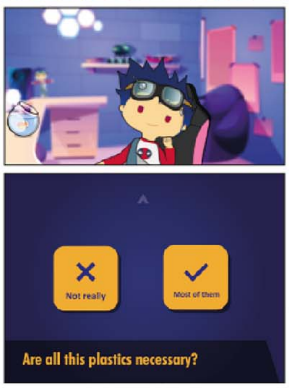
Wow! This is nothing alike to the one we have now. Plastics did a huge difference…



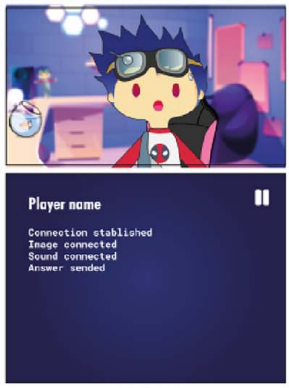
Can you tell me how much time is done the same quantity of plastic that would fulfill an Olympic swimming pool?



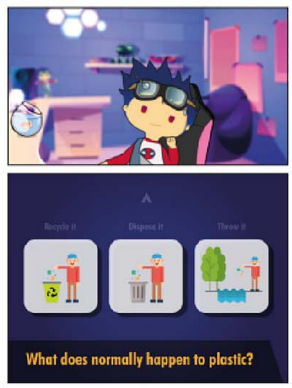
Almost 4 minutes… That means A LOT of swimming pools!



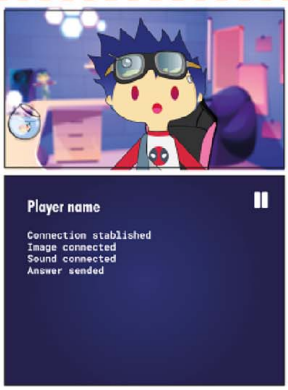
Well, I'm sure all of them are necessary, what do you think?



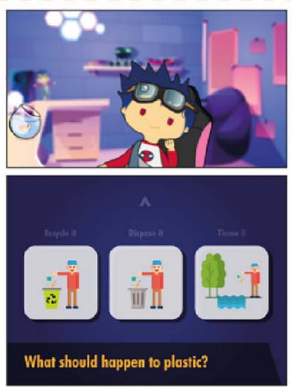
So, what do most people do with plastic after using it?



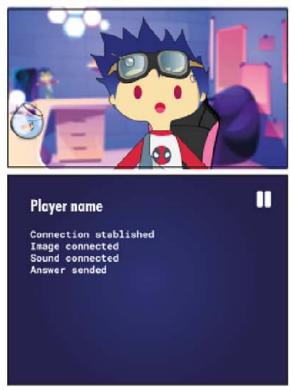
select between options



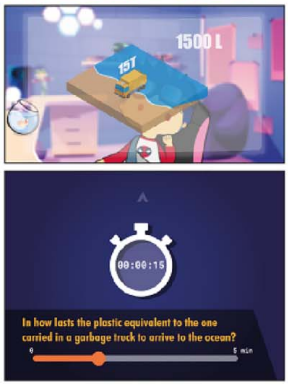
Well! Apparently only 9 out of 100 plastics had been recycled in your time, what do you think it needs to happen to plastic after being used?



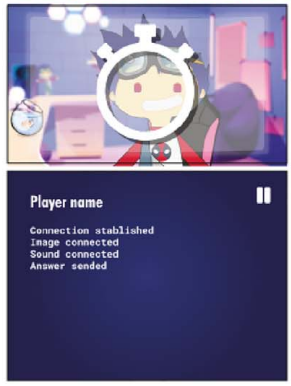
select between options



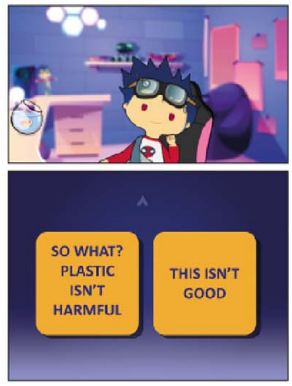
I've heard is important to recycle plastic. But that's not an infallible solution..



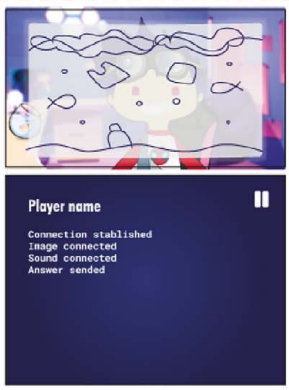
Do you know how much time requires to the equivalent to the plastic of a garbage truck full of plastic to arrive to the ocean?



1 minute! Every minute a truck full of plastic was dump in our oceans?

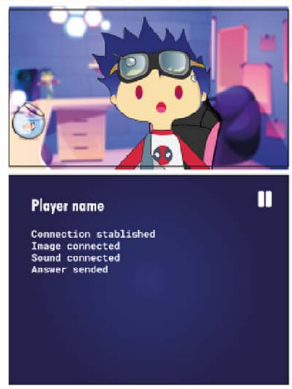


select option 1 or 2

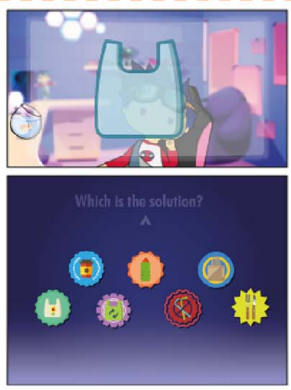


Okay! If I understood correctly, the year that you live, your ocean right now it looks like that.

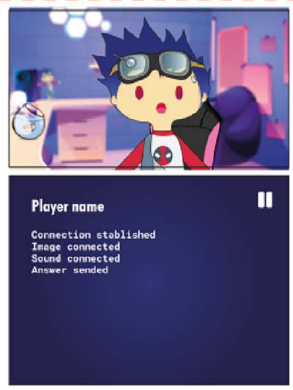
Can you help me to identify where the plastic comes from??



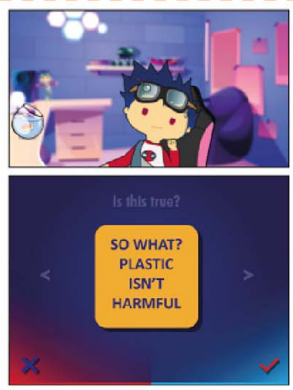
Wow, I couldn't manage it without your help! I'm so grateful!



match problems and solutions



YEAHHHHH!! WE DID IT!!!! The ocean will look amazing! We just need to remember…



say if the sentences are right or wrong

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