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Design of an Intrinsically Motivating AR Experience for Environmental Awareness

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Abstract

Augmented Reality seems a promising tool to provide engaging and effective educational experiences, thanks to its potentiality in stimulating intrinsic motivation, that could influence the learning process and the attitude of the users towards behaviours. This paper presents the Resized Plastic Augmented Reality learning experience, designed on the basis of Dunleavy's framework to provide a systemic overview of the microplastics issue to allow users to understand its mechanisms, educate them about their role in the system and help them to connect this information to their everyday actions.

Keywords: augmented reality (AR), sustainability, user experience, digital learning

1. Introduction

Sustainable development is defined as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." in the Brundtland Report of 1987 (Ceschin and Gaziulusoy, 2016). An evident contradiction emerges when comparing the words of this definition to our everyday life and to the way development has been taking place until nowadays. Many environmental issues need to be addressed immediately through a radical change to ensure this possibility to the next generations. One of these many issues is plastic pollution. In particular, the topic of microplastics has a great relevance due to its urgency and its impacts and dependencies on our everyday life. It articulates on different scales that go from the macroscopic overview of global phenomena, such as plastic waste trade or microplastics distribution in the different ocean basins, to the microscopic properties of the single plastic particle. The complexity of the microplastics problem requires a systemic approach to be effectively communicated, understood and addressed. For these reasons, it requires means to effectively show every single step of the overall polluting process and how the several elements of the system interact with each other.
Digital technologies can have a strategic role in addressing complex topics, as the microplastics one, in the field of sustainability awareness and education. Indeed, they provide a powerful aid in visualizing, demonstrating and emphasizing information and in making knowledge more accessible. This aspect can be considered valuable for scholastic education but also for social and environmental ones, that should be guaranteed through the offering of effective and engaging learning tools. Indeed, the design of innovative learning tools aiming at this purpose would extend the possibility to access knowledge to a larger audience and would also empower people to be able to respond to challenging issues that require quick reactions, such as the environmental ones.
Digital technologies in the field of education allow also to make abstract thinking more tangible. Specifically, the design of Augmented Reality (AR) learning environments has the potential to provide engaging and relevant educational experiences by making the user feel entertained, confident and

satisfied. In fact, AR "allows you to enrich the world with the latest technology, generating a unique combined interactive experience. Virtual images, which students can see right in the lecture hall, make the learning material more vivid and memorable." (Ivanko et al., 2018). AR has already proven its potentialities in previous research works in the field of childhood education (Yilmaz, 2016), molecular biology (Safadel and White, 2019) and mathematics (Chen, 2019), and many other educational fields (Barrow et al., 2019; Kellems et al., 2019; Yilmaz, 2016).

Starting from the assumption that nowadays AR is increasingly used in the field of individual education, the authors decided to adopt it in addressing an important and complex sustainable issue such as that of microplastics, in the design and development of an AR educational application named Resized Plastic.

Resized Plastic allows users to have control over the spatial dimension, exploring the topic of microplastic from several points of view through the use of Augmented Reality. So, the application will represent a useful tool to stimulate users' motivation and consequently positively affect their awareness and future choices.

2. Related topics

Several case studies and research works have been analysed to understand the potentiality of the use of digital technologies in educational contexts. Digital technologies can bring a sense of challenge to the learning experience, emphasizing the feeling of exploration that feeds the learner's curiosity by treating the content as a living resource exposed to the learner step by step, and not as something to passively absorb (Dunleavy, 2014; Malone, 1981). In their study Ronimus et al. (2014) aimed at determining how the level of challenge and the presence of an educational tool (named GraphoGame) managed to maintain children's engagement over a training period. This study suggested interesting hints about the role of these tools in educational experiences, proving that children using GraphoGame made more gains in reading and spelling compared to the children that received only traditional training, showing a good level of engagement and motivation while using the game. Game mechanics have also been part of the (re)development of public high schools in cities such as New York and Chicago, in a process defined as gamification of education (Selwyn, 2013).

AR technology is a suitable tool to communicate information through storytelling modality, using metaphors and fantasies to engage users through familiar experiences and facilitate the learning process. Dunleavy (2014) reported some interesting examples of AR applications that successfully motivated the user in educational activities, such as Wolf Runner and Zombies, Run. In both cases, the narrative serves as an input to activate physical exercise and indirectly raise awareness about the importance of a healthier lifestyle. More in general, Preradovic and Lesin (2016) described several benefits of applying digital tools to education through the use of storytelling, all of them supporting the fact that digital tools have the potential to increase learning experience by "extending knowledge of the world, acquiring operational skills, and developing dispositions to learn".

Moreover, surprising elements introduced in AR experiences communicate a magical feeling to the audience and boost users' curiosity, imagination, visualization capabilities and positive attitude, lowering their stress level and improving their learning performances. As exemplified by Yilmaz (2016), some smart toys have been used to enhance children's curiosity about the learning activity, integrating into the experience 3D models, animations and videos. This research highlighted how AR provided a magical feeling to the experience, causing a high degree of surprise and curiosity in the young learners. Safadel and White (2019) provided students with a three-dimensional model of macromolecules visible through AR to improve their learning experience during biology classes. The spatial visualization of certain complex systems, as in the case of biology, provides a better learning experience, especially for learners who present weak spatial skills. Similarly, Chen (2019) investigated how the use of AR improved motivation and self-confidence in students, affecting their performance and satisfaction in learning math. The results of the study showed that the AR group performed better than the non-AR group and high anxiety learners improved their learning performances. Moreover, the high anxiety learners improved their confidence and satisfaction by lowering their anxiety levels, thanks to the exploratory, hands-on and playful experience provided by AR.

AR experiences also found fertile ground in the field of environmental education, taking advantage of the potentialities of this technology to inspire and spread awareness on environmental sustainability. To name a few interesting case studies, Wildeverse (www.internetofelephants.com) is a mobile AR application by Internet of Elephants that serves as a platform to connect people directly with the frontlines of conservation, bringing attention to the stories of real wild animals. INDE developed a mobile AR application to raise awareness on the Northern White Rhinos extinction, bringing the photorealistic three-dimensional model of the last living animal alive (www.indestry.com). National Geographic launched an Instagram cover that allows users to see, projected in AR, the climate data expected for 2070 of twelve different cities around the globe (www.nationalgeographic.com). Changing Earth, a multisensory AR experience designed for museums, aims at improving the users' engagement in exhibitions and generating awareness about the dramatic outcomes of pollution on the environment (Gardoni et al., 2020). Unexpected Growth, an art installation on the 6th floor terrace of the Whitney Museum of American Art by Tamiko Thiel, aims at engaging the public on both the threat of plastic waste and coral bleaching caused by global warming (www.tamikothiel.com/unexpectedgrowth). MeshMinds, in collaboration with the UN Environment Programme (UNEP), created an AR experience that immerses the viewer in a virtual ocean populated by sea creatures made from plastic waste. By interacting with the environment, people can virtually clean the sea (www.unep.org).

3. Main Idea

Based on the research works presented in the previous section, authors make the hypothesis that the use of Augmented Reality (AR) can be beneficial for arising awareness on the theme of microplastics to both improve the learning process and motivate the users to change their behaviours.

With the aim of demonstrating this hypothesis, the authors developed an AR educational tool to be experienced individually at home, named Resized Plastic. Moreover, preliminary testing sessions have been organised with users to verify the effectiveness of the AR educational tool.

In particular, the Resized Plastic application has been designed and developed to provide a systemic overview of the microplastics issue, supporting users to understand its mechanisms, educating them about their role in the system and allowing them to connect this information to their everyday actions. Moreover, using AR, Resized Plastic allows users to visualize, interact and better understand abstract concepts and 3D data related to the microplastic issue by transposing them in real life. In fact, in order to design an "ideal learning experience" according to the Lampe and Hinske (2007) definition, Resized Plastic combines physical experience, virtual content and imagination.

The overall design activity has been focused on stimulating the users' "intrinsic motivation", which is one of the most important elements that affect learning activities and behavioural change (Lee et al., 2005; Leng et al., 2011, Liu et al., 2020).

Specifically, to effectively stimulate users' intrinsic motivation, the wireframe on which Resized Plastic has been designed is based on the Malone's framework (Malone, 1981) and on the Dunleavy's design principles (Dunleavy, 2014). Malone's research focused on computer games and aimed to understand "how instruction could be designed in a way that captivates and intrigues learners as well as educates them". As stated by Malone: "an activity is said to be intrinsically motivated if people engage in it 'for its own sake,' if they do not engage in the activity in order to receive some external reward such as money or status. I will use the words 'fun', 'interesting', 'captivating', 'appealing', and 'intrinsically motivating', all more or less interchangeably, to describe such activities". The elements which, according to this theory, make environments intrinsically motivating are: 1. Challenge; 2. Fantasy; and 3. Curiosity. So, Malone's production (1981) represents an interesting framework to understand how to design an engaging interactive learning experience. Similarly, Dunleavy identified three design principles as instructive, loosely connected to Malone's key elements of intrinsically motivating instruction: 1. Enable and then challenge ("Challenge" in Malone); 2. Drive by gamified story ("Fantasy" in Malone); and 3. See the unseen ("Curiosity" in Malone). He affirms that "these design principles can also be viewed as an attempt to either leverage the unique affordances of AR or minimize the limitations of the medium". Starting from this quote, Dunleavy's principles can be seen as a tentative to combine the aspects of utility and fun (Lee et al., 2005; Zhang et al., 2008), through AR experiences, and to apply them to the realm of education.

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3.1. Concept ideation

On the basis of the knowledge acquired by analysing the Malone's framework (1981) and the Dunleavy's design principles (2014), it was possible to set the base of the concept of Resized Plastic.

Resized Plastic is an AR educational tool that guides the learners through a journey to discover the phenomenon of microplastic pollution considering both the macroscopic overview of global phenomena and the microscopic properties of the single plastic particle. In fact, the AR tool allows the user to explore the microplastic issue adopting different levels of zoom. The system is composed of two interactive elements: a paper marker, made of two overlapping disks and a digital device (i.e., a tablet PC), on which the AR application is installed. The AR application can recognize five different configurations of the marker which can be obtained by rotating one disk on top of the other. Each of these configurations corresponds to the AR educational content related to the different levels of zoom. The user interacts with the physical marker and with the AR digital content, displayed after framing each configuration.

The main structure and interactions of Resized Plastic have been designed on the basis of "Challenge", "Fantasy" and "Curiosity" principles identified by Dunleavy (2014) and Malone (1981), to engage and intrinsically motivate the user during the learning experience.

The Dunleavy's principle "Enable and then challenge" ("Challenge" in Malone) consists in enabling the exploration of the topic of microplastics though a playful and interactive digital experience. In Resized Plastic the augmented contents are embedded in the environment, therefore hidden from the user until the interaction occurs, to stimulate the user's sense of challenge. To reach the goal of transmitting meaningful knowledge, the user is involved in the events that are taking place in AR as often as possible. This allows the user to connect the information to his/her role in the environmental issue. Every time the interaction occurs and the information is provided, visual and sound feedback are presented to the user, to clearly enable the users' understanding that the interaction has been successfully completed. To avoid the occurrence of cognitive overload during the User Experience, as proposed by Dunleavy (2014), some strategies have been applied to enable the user to frame the interaction before presenting the challenge. As an example, an initial tutorial has been designed to explain to the user how to interact with the marker and also to provide an index of the experience, useful to associate each of the five marker configurations with the relative educational content and level of zoom. Moreover, every time the user visualizes the first phase of each step, some instructions describing interaction modalities are provided, to guide him/her through the experience. Furthermore, a voice track, corresponding to the written content of each step, has been added to make it easier for the user to acquire the information while interacting with the digital environment.

Concerning the user interaction, a "magical" magnifying lens has been used as a metaphorical tool to investigate objects and information inside the AR application. The metaphor of the magnifying lens serves as the "fantasy" element introduces by the Dunleavy's principle "Drive by Gamified Story" ("Fantasy" in Malone). The lens has been introduced to increase the level of zoom of the microplastic issue, recalling the objective lenses of a microscope. Therefore, it has been included as a narrative element into the AR tool to help users to associate the interaction designed for this experience, with real life activities that they have probably already performed and, consequently, facilitate both the interaction with the application and the learning process. In addition, the possibility to interact with the marker through rotation can easily recall the same rotational movement required to zoom in/out contents, interacting with scientific tools, such as microscopes or binoculars.

In addition, the Dunleavy's principle "See the unseen" ("Curiosity" in Malone) in Resized Plastics takes advantage of the characteristics of AR to arouse curiosity in the user by providing a surprisingly magical feeling, associated with the experience of visualizing the virtual content combined with the reality. In fact, the camera of the device, as suggested by Dunleavy (2014), serves as a lens through which the digital content is superimposed on the real world. AR grants the possibility to easily visualize complex scenarios through 3D interactive visualizations. Therefore, AR, due to its nature, offers a great opportunity to easily communicate information which is difficult to visualize, as it happens with microplastics. To fully understand the microplastics issue, in fact, it is important to take into consideration the global dynamics of the environmental problem. AR allows the user to visualize the data in a more practical way, analysing each element of the system without losing the complete

picture. It also allows the visualization of the microscopic particles and the processes in which they are involved without abstracting them from their context. It makes the comprehension of abstract concepts easier by making them tangible, interactive and surprising, positively influencing user's willingness to make efforts in learning them. This sensation is reinforced by the presence in the experience of sensory curiosity (Malone, 1981). Bright colours, animated characters and music participate in making the experience proposed by Resized Plastics surprising. The user's curiosity is further stimulated by the visual feedback triggered by his/her actions, corresponding to animations used to exemplify the concept communicated or simply to engage the user with the narration.
Lastly, a further element that acts transversally within the adopted principles, has been introduced: the "choice". The element of choice plays a fundamental role in Resized Plastic. As described by Malone (1981), choice is considered to have a crucial role in increasing users' motivation to perform a task. Therefore, in this AR experience, the user has complete freedom to decide with which steps to interact with and in which order. The experience can be performed moving from the widest zoom to the narrowest one, from the narrowest one to the widest one or also mixing the steps. Indeed, the contents of each step are self-explanatory and the user can choose if interacting with each AR element or not. In this way, the user can explore the AR contents by simply following his/her curiosity.

4. Development of the Resized Plastic application

Once the concept has been defined and the theoretical framework has been applied to the design of the interactions, the overall educational experience has been designed in detail and a high-fidelity prototype of the AR application to be tested with users has been developed. The development process is explained in detail in the following sections.

4.1. Marker design and development

The Resized Plastic system is composed of an AR application and a maker printed on paper (Figure 1). During the educational experience, the user firstly acts on the marker, changing its configuration, then on the device, interacting with the digital content displayed after framing the marker. As output, the AR application provides animations, written content, sounds and audio descriptions. The overall experience is composed of the repetition of these inputs and outputs, because of the user interaction with the system.

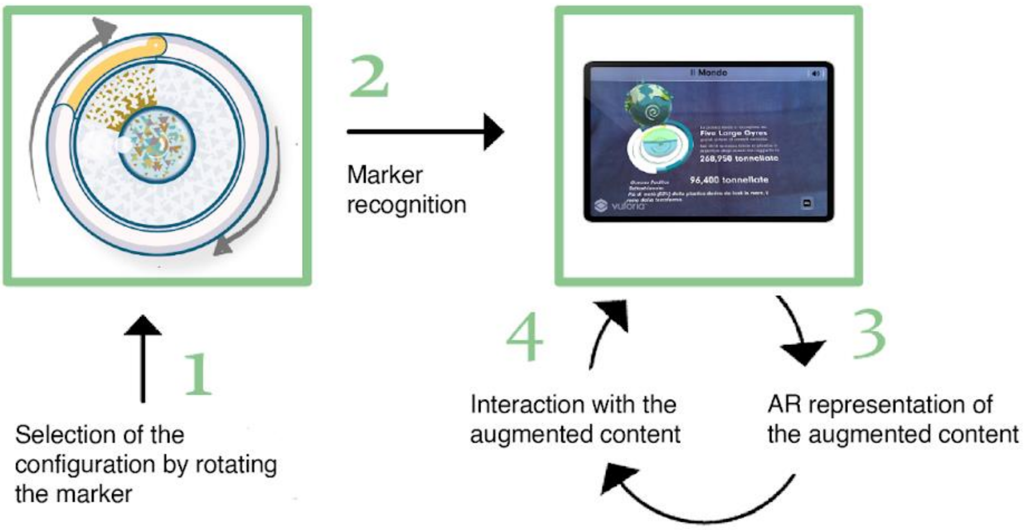

Figure 1. The structure of the interaction

The maker is composed of two paper disks with the same radius which can be easily cut out and assembled autonomously by the user (Figure 2). By overlapping them, the disc on the top displays

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only partially the other one. The two disks are kept together by a pin inserted in their centre, which allows their rotation, to obtain five different configurations. The design of the marker has been inspired by the optics of microscopes and by the colours and shapes of microplastics fragments. Two aesthetic features have been designed to help the user to orientate through the five different configurations. The white circle, at the centre of the rounded end of the coloured border, gets bigger as the user zooms in. The same happens for the units of the geometrical pattern.

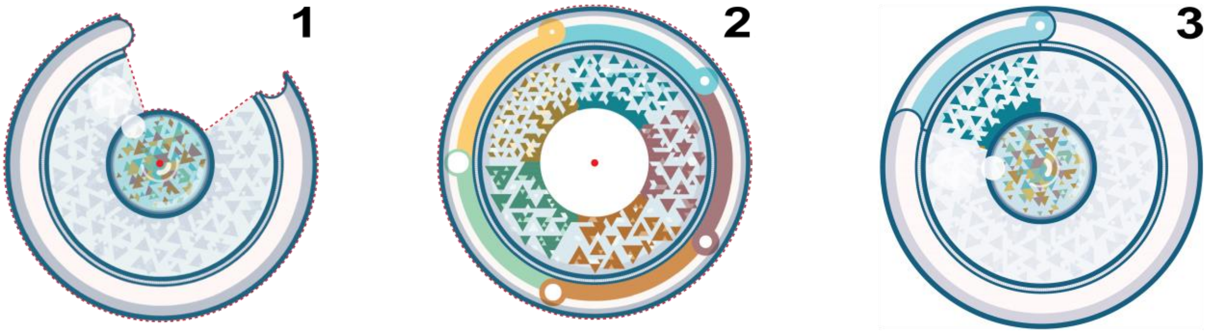

Figure 2. Marker components (1 and 2) and assembled configuration (3)

4.2. Structure of the AR application

The AR application, developed by using the Unity software (unity.com) and the Vuforia Engine (https://developer.vuforia.com/), is composed of two main sections. The first is an introductory section, divided into the Welcome Page, the Tutorial and the Index of the content. The second section is where the interactive learning experience takes place. It is represented by one single scene, the Main Scene, in which the user is asked to frame the marker to trigger the AR interactive content. From the Main Scene, the user is able to access five different sections of the learning experience, through the recognition of the corresponding marker configuration (Figure 3).

Figure 3. Correspondence between the five marker configurations and the educational content of the application.

The section named "World" (Figure 4) provides global data about the current plastic production and dispersion in the environment. Here the users can choose to manipulate a three-dimensional model of the world by scaling and rotating it, to easily tap on the interactive elements to access the information related to each macro-region of the world and to the Five Large Gyres, systems of spiralling currents responsible for the collection of most of the microplastics in the oceans. The data related to each site

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are provided together with a three-dimensional visual representation, to facilitate their comprehension and link the specific information to the global scenario.

"Ecosystem" section represents a cross-section of the marine environment (Figure 4). In this section the user is free to explore the environment by tapping on each of the interactive elements, characterized by the recognizable material. The main goal of this step, besides informing the users, is to surprise them with a dynamic and detailed representation of the marine ecosystem which has the purpose of representing the complexity of the microplastics issue from a systemic point of view.

Figure 4. The world and the ecosystem

"Living Beings" (Figure 5) focuses on the impact of plastic on both animals and humans, connecting our everyday choices and behaviours to their environmental consequences. This step is the most game-like of the five educational sections. In fact, the game-like activity, characterized by elements of interactivity and choice, stimulates a high level of motivation in the user, helping him/her to memorize the information and, possibly, influencing his/her future everyday behaviours. The user can choose a character between a sea turtle and a human and tap on some interactive objects to make the character move in that direction, in order to achieve information about the interaction between the character and that specific polluting element.

"Plastic Smog" displays information about the classification of microplastics (Figure 5). To make this information tangible, it provides size comparisons and a visual representation of the composition of microplastic samples. This data is provided through a three-dimensional visual representation, which facilitates its comprehension and memorisation. The size of the particles is made tangible by comparing their dimension with the one of a well-known object, such as a hatpin and a blood cell, while their distribution per variety is represented by visually highlighting their proportion in a reference sample.

Figure 5. Living beings and plastic smog

"Particle" focuses on the single microplastic unit, allowing the interaction with the highlighted elements to receive information about the toxicity of microplastics. "The Particle" presents a guided

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experience, organized in three steps, to discover the properties of a single microplastic particle. The first step introduces the user to the single particle, the second describes the absorption of toxic substances and the third the process of their release. The three-dimensional representation of the polluting process aids the comprehension of the information, making it less abstract and easier to memorise.

Figure 6. The particle

5. Testing session and discussion

After the design and development of the Resized Plastic AR application, some preliminary tests with 24 users have been conducted to investigate the effectiveness of the Resized Plastic AR educational tool in communicating the information and improving the attitude and behavioural intentions towards sustainability. In particular, the subjects have been divided in two groups: a control group and an experimental group. The same content regarding the microplastic issue has been proposed to the two groups. The control group acquired the information through a Power Point presentation while the experimental group through the Resized Plastic AR education tool. Then a questionnaire has been proposed to the two groups. The questionnaire has been developed taking into consideration similar works found in the literature (Mumtaz et al., 2017; Rese et al., 2017; Salloum et al., 2019) and it consisted in a variation of the TAM model by Davis (1989). The questionnaire is composed of four sections, mainly regarding: general information about the user concerning demographics, technology and sustainability familiarity (with open questions and ratings from 1 to 10); evaluation of the users' learning performance (with closed questions about the educational content of the experience); quality and engagement of the overall experience (with open questions, ratings from 1 to 10 and semantic differentials); evaluation of the users' acceptance of the educational tool (with ratings from 1 to 7).
The analysis of the results demonstrated that Resized Plastic has succeeded in transferring environmental knowledge to the users, who evaluated the application as an engaging, playful, and useful tool in understanding and memorizing concepts related to the microplastic issue, and that the experience had an impact on the users' behavioural process. Also, by comparing Resized Plastic to a more traditional tool as the Power Point presentation, it has been perceived by the users as more challenging, engaging, playful and useful, being associated with an interactive and colourful experience particularly suitable for a young audience.
From the information collected through the questionnaire and the debriefing activity performed with the experimental group, it can be deduced that the application of Malone's framework and Dunleavy's principles to the design of Resized Plastic has effectively aided in achieving the initial research goals. In particular, the metaphor of the magnifying lens and the consequent activity of exploring by zooming, designed for the application of the "Drive by gamified story (fantasy)" principle, can be considered successful. In fact, the users reported a good level of engagement and perceived ease of use of the application, aided by the presence of this narrative element which made the experience more accessible and enjoyable. Also, as suggested by the "See the unseen (curiosity)" principle, the possibility to present the information about microplastics through AR and the "magnifying" properties of the digital lens, effectively stimulated the users' curiosity and imagination, who defined the

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application as interesting, engaging, challenging, innovative and useful. Nevertheless, the application of the principle "Enable than challenge (challenge)" in Resized Plastic could be improved. Specifically, the absence of a clear end goal which could define the aim of the experience had an impact on its overall perception by the users, who found the fruition of some sections confusing. Concerning this aspect, a further improvement of the ease of use of the application could be done by providing the users a clearer goal connected to game-like interactions and by giving a more relevant role to the voice guide, as those has been evaluated as the preferred modalities to get access the information.

6. Conclusions

The paper presents an experimental research activity based on the hypothesis that the use of AR can be beneficial for arising awareness on the theme of microplastics to both improve the learning process and motivate the users to change their behaviours. To demonstrate the hypothesis, the Resized Plastic AR educational tool has been developed and then evaluated with users.

In the context of the design process of the application, the "intrinsic motivation" strategy has been used to influence the learning process and the attitude of the users towards their behaviours. In fact, it has been proven that intrinsic motivation has a particularly relevant role when talking about sustainable behaviours and the acquisition of knowledge about environmental issues (Liu et al., 2020). In addition, the strategies proposed by Dunleavy (2014) inspired by Malone (1981) have been chosen as a framework for the design of the intrinsically motivating AR learning tool about the topic of microplastics.

Consequently, some preliminary testing sessions with users have been performed. The analysis of the collected results demonstrated that Resized Plastic has succeeded in transferring knowledge to the users and, more in general, it has proven to have great potential in the educational field. Resized Plastic was well accepted by the users, who considered it useful, interesting, and engaging. It succeeded in informing the audience about the topic of microplastics through an intrinsically motivating experience, providing fertile ground for sustainable behavioural change. By testing it with users, AR has proven to be a promising learning tool, which can give a joyful learning experience to the audience and motivate people to enthusiastically improve their behaviours.

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