Universal Access in the Information Society
https://doi.org/10.1007/s10209-024-01092-4

LONG PAPER

Participatory design methods for sustainable interaction design: co-designing digital experiences for sustainability education

Gian Andrea Giacobone[1] · **Alessandro Pollini**[1] · **Diana Urquiza**[2] · **Konstantina Chouta**[2]

Accepted: 11 January 2024

Abstract
This paper analyses and presents the theoretical approaches, methodologies, techniques and results developed and obtained in the first stage of activities of GreenSCENT—Smart Citizen Education for a Green Future, a multi-disciplinary research project funded by the EC Horizon 2020 program, which aims to design and deliver Sustainability Education methods and technologies, as well as a competence framework, to improve the quality, the spread and the effectiveness of the Sustainability Education currently provided to students, citizens and institutions. In particular, this article describes how two main GreenSCENT technology-enhanced learning tools, the Air Quality App and the GreenVerse Interactive Platform, have been proposed, demonstrated and discussed with the GreenSCENT User Panels in three co-design workshops held in 2022 at the following various educational institutions: the Ellinogermaniki Agogi School in Athens, Greece, the Gimnazija Smart School and the University of Novi Sad, Serbia and the IES Raspall in Cardedeu, Spain. The activities explored an educational framework that led a group of students to co-create new educational methods and learning processes by both exploring the concept of the Air Quality App and experimenting with the GreenVerse Interactive Platform as a potential tool to stimulate reflective learning and sustainable actions that could have a positive impact on climate change. The ultimate aim of the article is to illustrate the utility and practicality of our approach for other researchers interested in the co-production of digital, physical, and hybrid educational technologies with the target audience to provide the teachers and, ultimately, the students with new interactive and immersive solutions that support Sustainability Education.

Keywords Participatory design · Co-design · Sustainability education · User experience research · Sustainable interaction design

1 Introduction

Sustainable development has been increasingly appearing in national governments' political agendas since the 1980s. One of the most relevant definitions from the Brundtland Report (1987) reads: "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" [1].

Nowadays, the individuals most affected by sustainability challenges, such as climate change, are not some imagined future generation, but young people alive today, as Sir David Attenborough stated at COP26 in November 2021. And, as Tomlinson, et al. [2] indicate, a future of collapse and limits does not appear in an instance but a society slowly transitions into it [3] and current western wasteful lifestyle cannot be maintained anymore.

Technological design is enthusiastically put at the centre of modern societies innovation, and that might bring design practitioners and researchers to illusorily tend to practise the discipline as if we were in the full availability of infinite resources, unbounded potential of technology, and knowledgeable users. Consequently, we encourage the increasing use of digital services for socialisation, communication, productivity and entertainment [4].

As already debated since the '1970s, the Social Design movement [5] turned the traditional act of designing for mass consumption into a more meaningful and committed-to-society process that served to answer more complex

✉ Gian Andrea Giacobone
gianandrea.giacobone@uninettunouniversity.net

[1] International Telematic University Uninettuno, Corso Vittorio Emanuele II, 39, 00186 Rome, Italy

[2] Barcelona Supercomputing Center (BSC), Plaça d'Eusebi Güell, 1-3, 08034 Barcelona, Spain

Published online: 14 February 2024

problems related to the real social, ecological, environmental, political and cultural needs of humanity [6, 7]. During few decades, this new conception of Design progressively evolved in a new design process of answering and solving problems related with human injustice, inequality, health issues, marginalisation, education, and finally sustainability, making design closer and widely accessible to individuals and organisations by fostering active social collaboration and participation among them [8, 9]. In that sense, Social Design brought the focus of modern designers from solely looking at technology innovation to novel shapes of active and aware citizenship and social integration [10–12].

Stemming from the roots of Social Design, this research will contribute to evolve the Sustainable Interaction Design field [13] as it will gather data towards devising processes, platforms, and tools that may catalyse societal transitions towards sustainability-through-design, i.e. how interactive systems can be used to promote more sustainable behaviours, as well as sustainability-in-design, i.e. how sustainability can be used as a critical lens in the design of interactive technologies themselves [14].

Moreover, the last 20 years have seen an increasing attention to Green Information Systems (IS) and to the contribution they can give to environmental sustainability by improving efficiency and effectiveness through automation, the provision of relevant information, and the establishment of better (more sustainable) services [15]. Green IS are focussing on objectives such as learning, data collection and awareness raising [16], but the literature is demonstrating that today's crisis is encouraging a holistic turn into regeneration and a cultural shift is required [17].

In this paper, we analyse and present the theoretical approaches, methodologies, techniques, and results developed and obtained in the first development stage of the project GreenSCENT—Smart Citizen Education for a Green Future. Funded by the European Commission Horizon 2020 program, GreenSCENT aims to design and deliver Sustainability Education methods and technologies, as well as a competence framework with the aim of improving the quality, the spread and the effectiveness of the Sustainability Education currently provided to students, citizens, and institutions.

This research integrates a user-centred, iterative, and participatory design approach that aims to respond adequately to new citizens' needs, ethical and intercultural dimensions, and to monitor and validate the socio-economic impact of the proposed solution. During the first year, we developed the guidelines and requirements that technical project partners need to develop the software service provision flows through mobile, distributed, and immersive technologies. This was achieved through co-design activities and co-creation practices that engaged the primary target users (students and teachers).

The practice of collective creativity in design has been present for nearly 40 years, under the name of participatory design [18]. In the 1970s, the Collective Resource Approach, a Scandinavian approach to design, was established to increase the value of workers' engagement in the development of new systems for the workplace. This approach brought the designers/researchers (experts of the systems) and workers to build on the workers' own experiences and provided them with the resources to be able to improve their current work condition [19, 20]. More recently, Maarten Pieters and Stefanie Jansen introduced the term co-creation as the "*transparent process of value creation in ongoing, productive collaboration with, and supported by, all relevant parties, with end-users playing a central role*" [21]. GreenSCENT co-creation actively involves heterogeneous panels of end-users, including pupils, teachers, researchers, professors, citizens, and entrepreneurs in a fully integrated development process, from the identification of global–local climate challenges to the implementation and tracking of behavioural change initiatives.

The co-creation design workshop has been used for assessing features and finding alternatives for current activities, seeking possible new directions against the outlined future possibilities (scenarios) or for collecting images of the futures without an immediate use for this information in mind (food for thought) [22]. Notwithstanding the increasing importance of co-production, fewer co-design studies have been conducted around collective sustainability actions.

Co-production involving several users and community members in identifying gaps, priorities and developing new solutions is urgently needed to assure the mobilisation of the society. In particular, exploration of the potential of technology as part of services to support people's behavioural change and novel habits are increasingly important.

2 Methodological approach

To explore the understanding of technology for the support of Sustainability Education innovation, we organised three main co-design workshops using different co-design approaches, both with interactive tools and analogue activities, with the aim to gather information about how Sustainability Education is perceived by attendees, explore attitudes towards the role of technology in addressing sustainable behavioural change, and understand stakeholders' visions of how emerging technologies could be utilised to benefit the activation of communities.

At the methodological level, this research proposes to implement local User Panels [23], a qualitative methodology that relies on a group of pre-recruited end-users

whom the research team worked with throughout following a human-centred and participatory design approach User Panels act as a form of longitudinal research that allows the researchers to observe the current European educational scenario from different actors' perspectives, experiences, and learning needs. In particular, the involved users came from three socio-cultural contexts, i.e., Novi Sad in Serbia, Athens in Greece, and Barcelona in Spain. User Panels are allowing the researchers to identify and solve the emerging educational challenges that hinder the European educational system from teaching pro-environmental behaviours to its citizens, especially among the younger generations.

We adopted the User Panels' participatory activities to repeatedly collect qualitative data from the end-users' requirements and to obtain valuable insights to develop, test and validate both the GreenSCENT educational framework and the hybrid educational experiences provided by the technological demonstrators. In particular, the scope of that methodological approach is to transform user requirements into design opportunities to design new strategic pedagogies—including collaborative learning, debate, research-based learning, and inquiry-based learning—that can motivate people to adopt sustainable and environmentally aware behaviours.

This article describes how two main Sustainability Education technologies, the Air Quality App and the GreenVerse Interactive Platform, have been proposed, demonstrated and discussed with the user panels in three different co-design workshops held in 2022 at the following educational institutions: the Ellinogermaniki Agogi School in Athens, Greece, the Gimnazija Smart School in Novi Sad and the University of Novi Sad, Serbia, and the IES Raspall in Cardedeu, Spain. In particular, the novel technologies have been explored through adopting seven specific co-design methods defined by the authors—four of them have been applied for the design of the Air Quality App, and the other three for the GreenVerse Interactive Platform—which are explored and described in detail in Sects. 3.1–4.3. The research and design scope, the target participants and the level of maturity of the technology, represent the three main criteria for the definition and adaptation of the methods.

The workshops intended to explore new future educational scenarios aiming at fostering awareness of sustainability among young people respectively through exploratory research for a new product and collection of insights for the design process of the tool, and the adoption of immersive technology-enhanced learning experiences. Beyond the co-design, the objectives were to go beyond the acquisition of formal knowledge to foster:

- the promotion of dialogues, negotiation and interpersonal skills;
- the development of a matured personal point of view;
- the ability to relate scientific knowledge to systems of personal and social values.

We reflected on these aspects to analyse how they could affect the individual's decision-making processes to adopt responsible behavioural choices [24, 25]. In particular, the activities explored an educational framework that led a group of students to co-create new educational methods and learning processes by both exploring the concept of the Air Quality App and experimenting with the GreenVerse Interactive Platform, as potential tools to stimulate reflective learning and sustainable actions that could have a positive impact on climate change.

The ultimate scope of the article is to illustrate the utility and practicality of our approach for other researchers interested in the co-production of digital, physical, and hybrid educational technologies with the target audience to provide the teachers and, ultimately, the students with new interactive and immersive solutions that support Sustainability Education.

3 Air quality app: exploratory and design research

The air quality application implements an e-learning experience using gamification as an important element for exploring air quality competences of students as well as of teachers and parents through augmented reality (AR). We report on three experiments in which character design, storytelling and rapid paper prototyping design revealed important insights for the design research team to inform the design decisions of the AR application, objective, and functionalities. Prior to these co-design experiments, we conducted interviews with educators, parents, and students as preparatory activities.

When designing products and services tailored for children, it is essential to recognise that they are the end-users, which means they should be involved in the initial phases of the design process. We decided to start the exploration phase of the design concept with co-design workshops [26].

The value of the co-design workshop focuses on envisioning solutions through creativity, and brings the users to the centre of the design activities. The participants were faced with the challenge of creating a game and solving questions around air quality through design, storytelling, and prototyping. Storytelling enables rational, emotional, and experienced relationship learning. By asking users to create narratives around a topic, we were able to gain a deeper

understanding of users' perspectives, beliefs, values, and behaviours.

Stories can help us to identify patterns, themes, and trends. By examining multiple stories from different users, we were able to identify commonalities and differences in users' experiences and create a more comprehensive understanding of the approach the users have towards air quality topics.

Using rapid paper prototyping allowed us to understand how students relate to the different Air Quality concepts, how they included them into a story and finally how they could create a game that integrates gamification into the learning process [27].

Co-design methods were used to explore the solution to the problem statement: how could we co-design an air quality game that engages and empowers students to learn and develop new competences around air quality topics. Time constraints were implemented to ensure participants would explore the process without getting lost in the details as well a way to boost activity and improve the outcome [28]. An important element in each activity was the presentation of each idea to the rest of the group. The activities were designed to last 2.5 h in total.

3.1 Method 1: Basic concepts of air quality class

Objective. Identify the concepts that come to the mind of the students when talking about Air Quality, explore with them some basic knowledge about air quality and give them enough information to enforce playing with the obtained new learnings.

Target. There were three iterations on this activity: the Greek Panel involved seven students (from 8 to 10 years old), educators and parents of variable age; the Serbian User Panel engaged with twelve students of secondary education (14–17 years old), and educators of different ages and backgrounds; the Spanish Panel engaged two groups of 20–30 students from secondary school (12–15 years old). When conducting the workshops with the researchers group, we skipped the air quality class, since they already had knowledge of the basic concepts of air quality.

Materials. Computer with internet and projector in a classroom.

Procedure. A facilitator offered a 30 min class, beginning with the open question of what comes to your mind when you hear the phrase "Air Quality". This question prompted the participants to reflect on what comes to their mind when thinking about Air Quality as well as introduced the topics of discussion during the rest of the workshop. The lesson covered the following topics in a simple and friendly form:

- What is air quality and how is it measured?
- Principal sources of air pollution, primary and secondary pollutants.
- How to read a map of air quality?
- Effects on health from air pollution, sensitive groups needs regarding air quality;
- The lack of geographical boundaries when it comes to air quality.

The lesson made use of infographics, videos, an air quality interactive map and a white board to fill in with the responses, with the goal of making the lesson interactive and friendly. This activity was the context setup for the following activities, since air quality is not included in the curriculum of any specific grade, the goal was to offer a quick introduction and explore the first impressions of students regarding air quality.

3.2 Method 2: Avatar design

Objective. Engage with the participants, break the ice and introduce them to the workshop activities and at the same time use analogies or metaphors to create characters that relate to air quality problems in their day to day lives [29].

Target. There were four iterations on this activity: the Greek Panel involved seven students (from 8 to 10 years old), educators and parents of variable age; the Serbian User Panel engaged with twelve students of secondary education (14–17 years old), educators of different ages and backgrounds; the Researchers group involved ten climate and air quality researchers from variable age; the Spanish Panel engaged two groups of 20–30 students from secondary school (12–15 years old).

Materials. Plasteline of different colours, at least two different ones for each participant.

Procedure. This activity was designed to last for 30 min. Each participant had to create a different avatar, intending it as an individual activity. The first step of the co-design process was to start by a simple metaphor game where the participants had to create an avatar that was somehow related to air quality with the premise that this character would be later used as an avatar to create a game. The relationships between real and imaginary avatars are encouraged.

Some examples of avatars were:

- "My avatar is a bird since it's always flying around, it gets directly affected by the bad air quality of the city and gets sick";
- "My avatar is a magical clown that has allergies so every time there is bad air quality it's cheeks get big and red because he has trouble breathing";
- "My avatar is a penguin, because with global warming and the CO_2 emissions they will lose their home in the glaciers".

In particular, the third example illustrates something that we found several times during the workshops, the misconceptions the students have with greenhouse gases and air pollutants, this helped us inform the curriculum design of some of the lessons. An important insight here is the need to provide clear and simple information to distinguish greenhouse gases and air pollutants.

3.3 Method 3: Storytelling

Objective. Participants adopt the role of storytellers in groups where at least one of the avatars of the group was the principal character of the story (Fig. 1).

Target. There were four iterations on this activity: the Greek Panel involved seven students (from 8 to 10 years old), educators and parents of variable age; the Serbian User Panel engaged with twelve students of secondary education (14–17 years old), educators of different ages and backgrounds; the Researchers group involved ten climate and air quality researchers from variable age; the Spanish Panel engaged two groups of 20–30 students from secondary school (12–15 years old).

Materials. Plasteline, wood blocks from different colours and shapes.

Procedure. This activity was designed to last for 50 min. Groups of 3 or 4 participants were made. Storytelling allowed participants to personalise their experiences and perspectives, it worked to share concerns, as well as evoke emotions and convey experiences so they could relate stories of air quality to their everyday lives. The participants were given the task of creating stories around an air quality topic, a series of topics are randomly distributed in the groups to help them have an initial condition, for example if they were unsure of what to talk about we offer cards with topics like "sources of air pollution", so they could have a prompt and play with ideas around topics that were shown in the air quality class at the beginning of the workshop.

There were two rounds of this activity, each group should share with the rest of the workshop each of the stories. The first round was designed as a warm-up. After the presentation of the first story, a quick discussion and feedback was held on the elements that help to create a better story: the plot, characters, a conflict, and a resolution. For the second round, participants tend to create more complex stories with a challenge related to air quality, given that the feedback is integrated in the process (Fig. 2).

An example of story that we heard:

> "This family had two pets that they really loved, but they started feeling bad because of the exhaust fumes of the cars. They went on hunger strike to make the girl understand something was wrong and come ask them. When they told the girl about the problem, she took some actions: she informed the neighbours, she started biking/walking to school and convinced schoolmates/family/neighbours to do the same, she started turning off the lights at home when they were not needed. The air quality improved and the animals started feeling well again".

3.4 Method 4: Rapid prototyping

Objective. Create paper rapid prototypes of the envisioned game where storytelling had an important role in the design and air quality topics were the basis of the story.

Target. There were four iterations on this activity: the Greek Panel involved seven students (from 8–10 years old), educators and parents of variable age; the Serbian

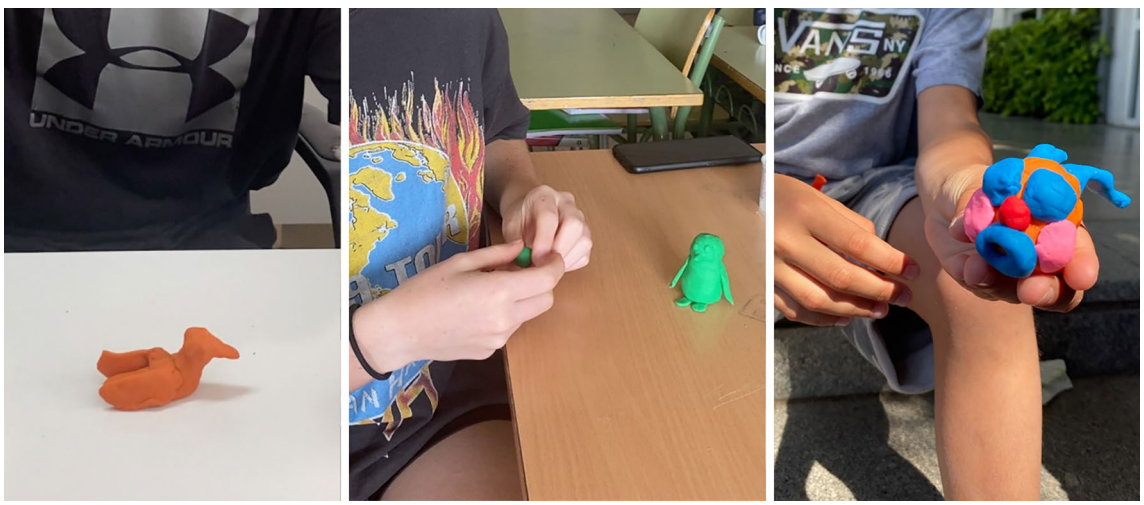

Fig. 1 Students creating different avatars for their stories

Fig. 2 By listening and analysing the stories the participants shared, we identified key concepts, values, and priorities that inform their relationship to air quality, which informed the development and design of a digital solution, in this case the Air Quality App

User Panel engaged with twelve students of secondary education (14–17 years old), educators of different ages and backgrounds; the Researchers group involved ten climate and air quality researchers from variable age; the Spain Cardedeu group engaged two groups of 20–30 students from secondary school (12–15 years old).

Materials. Blank mobile paper printed prototypes and different colour markers.

Procedure. This activity was designed to last for 50 min. Groups of 3 or 4 participants were made. A break between the Storytelling and the rapid prototyping was recommended.

The task consisted of designing three different mobile screens to illustrate how the game works; blank printed mobile prototypes were distributed to the participants in groups. The participants were encouraged to make use of storytelling with the premise "*every great game comes from a great story*", they were free to choose any avatar they had created, a new one or no avatar at all. If the facilitators observed the groups were struggling to create games, some random air quality topics were assigned.

The game needed to have a story, a challenge for the users in relationship with air quality themes. Two rounds were made, and every group presented their idea at the end of each round. An example of games that we saw (Fig. 3):

> "Since my avatar was a worm, it always hides away if the air quality is bad, so if the dice tells you that the air quality is bad today the worm has a more difficult challenge to get back home to the trees, but if the air quality is good his challenge is easier, he wins when he manages to arrive home during a whole week".

Fig. 3 Examples of paper prototypes created by one of the teams that participated in the co-creation workshops. This co-design of a game provided us valuable feedback on how to use storytelling through gamification to enhance learning about air quality. By engaging students in a fun and interactive learning experience, we help them develop a deeper understanding of key concepts and build skills to address air quality challenges in their day to day lives

4 Interactive documentary: working prototype exploration

The activities presented in this section are related to the experimentation of new educational scenarios in the GreenVerse Interactive Platform, a digital tool that enables students, teachers, and European citizens to acquire knowledge, skills, and attitudes to tackle environmental challenges related to the European Green Deal areas, through an augmented learning system. The digital tool is based on 360° environments, capable of articulating immersive information and narratives that enrich the quality of the user's learning experience.

The main objective of the co-design was to test and validate the user experience of the GreenVerse Interactive documentary demonstrator by involving a group of young students in a co-design session to improve the overall usability and accessibility of the prototype itself (see Fig. 4).

The researchers guided the participants to interact with particular features of the demonstrator to identify whether the main aspects and functions of the interface should be maintained, because they are helpful and pleasant to use or they should be improved if there are limitations in comprehension and usage. The evaluation aimed to collect several impressions about the understanding and easiness of the prototype to improve its functions through the participatory and inclusive contribution of the participants. The goal was also to collect several design concepts and ideas from the students as a design material to implement new features that could improve the usability of the final prototype.

These activities also explored the whole process of conception, planning and development of an interactive documentary. The methodology aimed to understand if the qualities of the GreenVerse platform would be accessible and intuitive enough to empower younger users to upload and assemble multimedia content on the application autonomously. That would allow users to generate 360° interactive environments and, thus, provide an immersive experience linked to Sustainability Education.

The GreenVerse educational scenario focussed on particular educational challenges on natural, cultural and societal heritage to:

- Promote awareness among young people of the importance of our common World Heritage;
- Encourage the young generation to actively become involved in heritage conservation on a local, as well as on a global level;
- Develop effective educational approaches and materials by working in synergy with educators and heritage conservation experts to introduce World Heritage Education into the curricula of secondary schools around the world.

Fig. 4 Researchers presenting to the students the functionalities of the GreenVerse Interactive documentary tool

4.1 Method 5: Future GreenVerse scenario

Objective. To introduce the learning experience design by focussing on a future scenario of educational challenges related to environmental sustainability. We aimed to investigate the main current problems that occur in the present's learning environment and successively envision new educational solutions that would solve those educational challenges together with the participants.

Target. For each European institution, the activity involved some teachers and parents of the corresponding User Panel. The Greek Panel involved four educators and two parents of variable age, divided into one male and five females. The Serbian User Panel engaged with thirteen educators of different ages, divided into four males and nine females. Two researchers coordinated the activities as facilitators.

Materials. We used a laptop and a projector to show the objectives of the activity through a short slide presentation. Some notebooks and pens were used to collect data during the session.

Procedure. This activity was designed to last for 30 min. We experimented with co-design activities proposing a referential future scenario in which the GreenVerse was expected to be utilised during a learning experience based on educational challenges related to environmental sustainability. The scenario was the following:

> "Martin, who is a passionate middle-aged high-school teacher and environmental enthusiast, learns about Sustainability Education. When he was young, Martin loved film-making. He dreamed of becoming a famous director producing engaging movies able to convey positive social messages. This passion may be why, when he learns about Sustainability Education, Martin decides to experiment with an interactive movie post-production tool.
> Martin downloads a concise user-manual of the tool and begins experimenting with it. He finds the software to be rich in features and easy to use, especially powerful when used to enrich and connect 360° panoramic video fragments.
> Martin knows he can use a 360° inexpensive video camera that the high-school where he works recently bought. He then decides to organise an educational visit to a waste management plant. He asks the plant manager permission—for him and his students—to record some operations, and upon receiving consent, Martin and his class, go to the plant for a one day visit and shooting session.
> Martin places and activates the 360° camera in a few selected plant locations to record the main process steps. While the plant manager explains the process, his students listen and record explanations while taking pictures, short videos, and notes. All students can do that by using their smartphones, equipped with the content collection app.
> When back in class, Martin uploads the 360° panoramic recordings on the platform. Then he and his students begin to use the immersive interactive documentary authoring tool. They start working cooperatively to link the immersive clips in a virtual tour. They enrich every clip with additional interactive elements coming from the recordings they made that very day. Martin and his students preview the resulting interactive documentary and find it engaging and useful. They add other content from the platform to further improve it".

Both workshops foresaw the proposition of this envisioning scenario to introduce the work with the preliminary prototype that has been respectively focussed:

- In Athens, on the interactive documentary storyboarding, meaning the definition of the documentary scope and concept, the sequencing of the contents and the structure of the interactions. The storyboard has then been used to generate 360° interactive environments in the GreenVerse;
- In Novi Sad, on the paper prototyping of the immersive experience, meaning the use of a spherical grid paper template enabling the students to figure out what the model of the interactive environment was. Working on the paper model allowed the students to gather the proper dimensions and visual resolution of their storyboard contents.

4.2 Method 6: Interactive documentary storyboarding

Objective. To experiment with the Interactive Documentary concept and prototype through the creation of immersive and interactive scenarios: at first as a storyboard, and then as an interactive mock-up directly on the GreenVerse platform prototype. The storyboard should highlight a particular educational challenge related to environmental sustainability. We encouraged each student to perform in-field activities around the school to collect information material and real-life evidence addressing environmental issues to recreate a real journalistic reporting experience.

Target users. The co-design activities were carried out in collaboration with the Ellinogermaniki Agogi School in Athens, Greece, which allowed us to involve a group of local students enrolled in secondary school courses. The recruitment process was conducted by the coordinator of the Greek user panel and involved ten motivated students

between 13 and 15 years old, six females and four males. Two researchers coordinated the activities as facilitators, introducing the workshop objectives and supporting the students during all the research and co-design phases. Instead, the user panel coordinator and a school teacher supervised the working group during the workshop activities.

Material. Given the hybrid nature of the activities, the workshop utilised two distinct typologies of design material: analogue and digital. We gave students pens, markers and A3 sheets as analogue resources to collect ideas for their design work.

For the digital activities, the school provided the students with a tablet equipped with Google Suite programs to record and collect multimedia resources from the real-life context and upload them in the tool to develop interactive documentaries. Again, we used a projector and two laptops to show the objectives of the workshop and the functionality of the GreenVerse demonstrator. The laptops were used to conduct the co-design activities with the students, specifically to help them interact with the digital demonstrator.

Preliminary activity. Before starting the activity, we held a brief discussion with the students, in collaboration with the coordinators of the local user panel, to explain the objectives of the research and align the workshop experience with the student's knowledge and skills towards Sustainability Education and digital literacy.

4.3 Method 7: Paper prototyping: interaction modelling

Objectives. The scope of the method was to test and understand if the GreenVerse Interactive Platform would provide university students with inclusive alternatives to design 360° environments capable of generating immersive experiences on Sustainability Education, also through analogical and hybrid methods [30], particularly to:

- explore students' design process to translate a particular environmental challenge into an interactive documentary with the aim to improve the accessibility and comprehension of each stage of the overall educational procedure;
- explore the level of inclusion of the demonstrator by analysing new ways of using the platform with limited resources—for instance, the lack of internet connection, electricity, or digital skills—to understand to which extent these technologies were able to provide engaging and immersive educational experiences in low resources scenarios.

Target. The co-design activities were performed in collaboration with the Faculty of Science in Novi Sad, Serbia. The institution involved a group of local university students enrolled in the Department of Geography, Tourism and Hotel Management. The recruitment step was performed by two coordinators of the Serbian panel.

Twelve students were involved in the workshop, five females and seven males, aged between 20 and 23 years. Like the Greek panel, two researchers coordinated the workshop as facilitators. They introduced the objectives and expected outcomes of the workshop to the students and helped them conduct the activities in each co-design phase, especially while implementing their ideas in interactive documentaries. The coordinators of the Serbian panel acted as observers of the working group during the workshop.

Material. During the first stages of the research, the students used their mobile devices to collect evidence around the university campus. The ideation phase for the interactive scenarios was conducted with personal notebooks and smartphones. In particular, the students were provided with paper-based templates representing a 360° spherical space on which it was possible to prototype interactive scenarios with tangible material (see Fig. 5).

Preliminary activity. We held a short discussion with the students, in collaboration with the Serbian user panel manager, to explain the objectives of the research and align the workshop experience with the students' knowledge and skills on environmental sustainability issues and digital literature.

Procedure for Module 6 and Module 7. Notwithstanding the specific nature of the modules, their procedure might be presented as follows. At the beginning of each module, the researchers presented to the students the objectives and the expected results of the activities through a short plenary presentation. They were structured in three macro steps:

1. Exploring and discovering;
2. Reflecting, consolidating, and defining the content;
3. Make it interactive.

The first phase consisted of an exploratory activity in a real-life context. We provided the student groups with tablets to collect evidence addressing sustainability around the school. The material served as a multimedia resource to draw the educational story. The students were free to collect evidence in different formats, such as photos, videos, or audio. In the second phase, the procedure was slightly differentiated:

- For the storyboarding, we provided students with A3 sheets, pens, and markers to describe their stories through the storyboard technique (see Fig. 6). The activity served to reflect and delineate the objectives of the documentary,

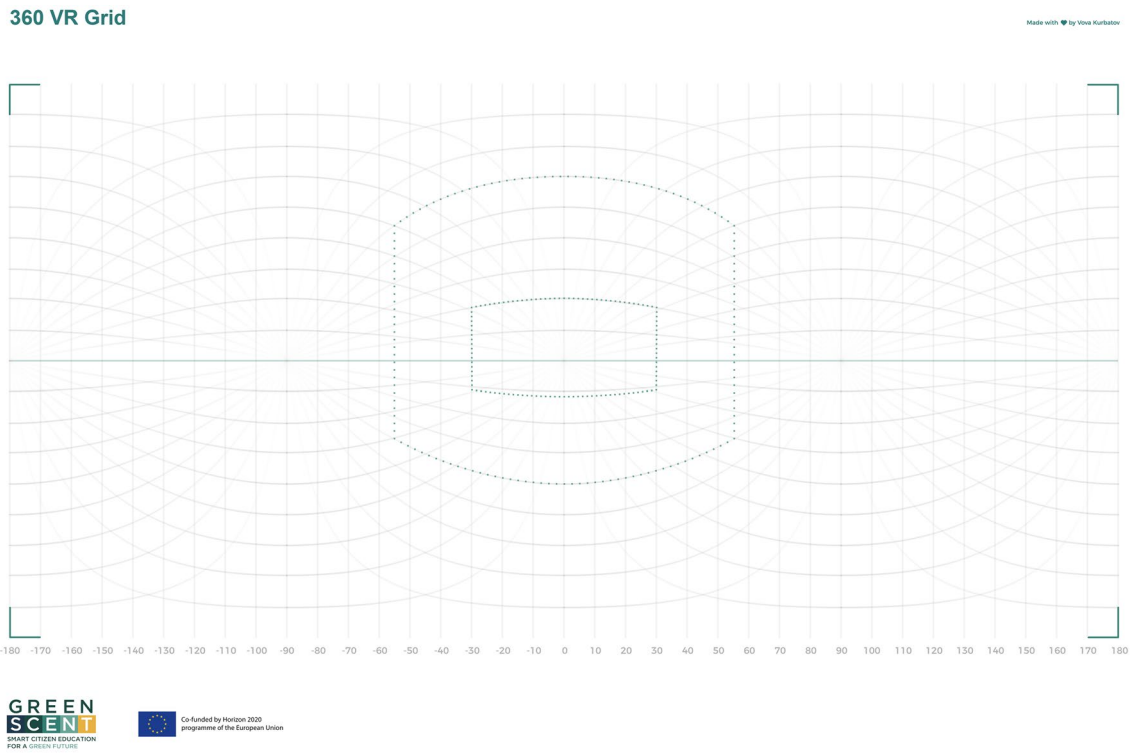

Fig. 5 Representation of the 360° paper-based template

define the logic and the steps of interaction, and select the evidence to be used to design their educational content;

- For the paper prototyping and modelling, we gave students paper material to describe their narratives using the storyboard technique and then with 360° paper-based prototypes to transform their stories into raw prototypes. Thanks to those material templates, the students represented not only every interaction step of the story but also the spatial arrangement of the multimedia contents quickly and without any technical constraints linked to the functional limits of the demonstrator.

Fig. 6 Students producing an interactive documentary by structuring their narration using a textual storyboard. The structure contains the selected multimedia resources collected in the first phase of the co-design activities

Finally, in the third step, we supported the students in translating their paper-based storyboards and models into immersive scenarios by interacting with the demonstrator. In that phase, the students were able to evaluate the usability and accessibility of the prototype during the participatory development of their immersive scenarios on its digital system.

The workshop activities lasted 2.5 h, and we divided the participants into five two-people groups to facilitate the activities. We structured the workshop with various learning-by-doing activities, which led the students to personally conceive an educational story related to sustainability by developing an immersive and interactive documentary using the demonstrator.

The process encouraged the students to gather information and evidence from their local context to highlight particular environmental issues, which would be used as multimedia resources to produce the interactive documentary. In that case, the workshop explored all the phases of developing an immersive scenario, from the preparatory phase that trained the students to structure their educational stories to the final stage, in which the latter came alive on the platform. Those

activities were also useful to test and assess the capabilities of the early version of the prototype in a controlled environment to closely understand how it is perceived and utilised by people and how it behaves while interacting with them in a real educational scenario.

5 Results and workshop evaluation

During the co-creation workshops we were able to gather insights that help us understand the effectiveness of the research methodologies applied, through the observation of the participants' behaviours, reactions, and considerations expressed. The analysis highlighted several reflections that allowed the evaluation of the methodologies adopted to conduct the co-design activities. The feedback received from the participants helped improve the use and functionality of the demonstrators, in terms of accessibility and usability of the systems.

In particular, we report some of the reflections related to the qualitative analysis of the outcomes, by using three main criteria:

- Understandability;
- Engagement;
- Perceived value.

5.1 Air quality application

The co-design workshops created an environment for the participants to create narratives that approach the topic of air quality and relate to it in personal and unique ways. The participants draw inspiration from their daily life experiences; thus, many of the stories they created were related to their specific surroundings. Since the air quality topic is not part of the official educational curriculum of the countries where the workshops were held, in many cases the students lacked pre-existing knowledge of the topic. We detected a confusion of air quality with other environmental issues and a lack of solid understanding of air quality and its impacts.

The delivery of the air quality lesson at the beginning of the workshop provided the participants with some notions on the topic and helped canalize their creativity towards building more relevant stories. We also observed that reminding the participants about the information shared during the lesson helped them to maintain the focus of their narratives on air quality. However, we witnessed cases where it was extremely hard to help participants focus back on air quality, as they were experiencing a significant confusion with other environmental topics, more familiar to them due to their surroundings, such as water pollution and waste management. Misconceptions and a lack of connection to the topic can make it difficult to engage students and motivate them to learn more about the topic. This is an important insight that will guide us in the design and development of the Air Quality application as well as the preparation of educational materials and strategies that can effectively communicate the relevance and importance of air quality.

For a great part of the stories, we detected that participants often attributed the role of the messenger of problematic air quality to non-human elements, enforcing their preconception that humans are not able to see the problem and highlighting the challenge of making the invisible visible. The use of AR technology can help overcome this challenge and contribute to making air quality visible.

Through co-design activities, we were able to explore the state of air quality education across different school grades. By involving students in the process, we ensured that their perspectives were considered, which will inform the design decisions of the development of the application and hopefully lead to more engaging and effective educational experiences.

In the previous interviews with researchers, parents, and teachers we found that teachers play a key role in the implementation of new digital resources in the teaching process. It is indispensable that teachers understand in depth how it works and be able to detect its value for learning. Limited time both in the classroom and for the preparation of the teaching material is one of the main struggles teachers face and influences their willingness to try and incorporate new tools in their teaching methods.

Another constraint is the predisposal of the teachers to explore innovative approaches or the lack of it. In the first round of interviews with teachers and parents, we found out about the different approaches educators adopt; and thus, we defined two different types of educators that summarise all the findings from the interviews: (a) educators motivated to explore topics beyond the official school curriculum and make use of innovative tools in the classroom and, (b) educators that follow strictly the official curriculum and lack motivation to explore new teaching approaches, as this would affect the already busy school dynamic. This insight was validated in the co-design activities, the profiles we have identified appeared in the different sessions that were held.

Having identified the main constraints that interfere with the educators' motivation to make use of such tools helps disclose actionable insights to be taken into consideration during the design phase of the AR app for air quality. The creation of a broad resource library for teachers with guides, infographics, glossaries, contextual information about air quality, video tutorials and ready-to-use educational activities can act as a support system, increase the uptake of the tool and contribute in bridging the gap between the two different profiles of educators.

Since air quality does not form part of the official school curriculum in the studied countries, the subject is often merged with the environmental education subject; and therefore, it would be beneficial to create support material that helps the teachers to relate them. Video tutorial was mentioned as the best tool for guiding teachers on how to introduce the subject of air quality and provide the lesson using innovative tools, such as the AR Air Quality app. Providing the lesson in innovative ways has a direct impact on the motivation of students to participate; however, it is crucial to create relatable scenarios in the storyline of the app to help connect the content of the lesson to the daily life experiences of the students, as this helps maximise the educational impact.

5.2 Interactive documentary

The participants conducted the activities of both workshops related to the GreenVerse prototype according to the intended objectives set by the research. Dividing the activities into three macro-phases made the objectives and outcomes expected from each step simple to understand and to be carried out by the students. Adopting hands-on activities during the workshop stimulated the participants' interest because it allowed them to translate theoretical learning related to Sustainability Education into practical activities. In that sense, the activities encouraged students to elaborate their knowledge about sustainability into practical actions, through which they were able to directly observe, measure, and evaluate the impact of their behaviours in real-life scenarios [31]. The time spent to conduct the activities was appropriate to their complexity.

The in-field exploration and collection of evidence allowed the students to relate themselves to nature by experiencing real-life situations. This enriched their awareness of the current condition of their local context and, hence, created more interest and motivation in its preservation and care.

Playing the role of a journalist also encouraged many students to participate actively in data collection by conducting direct interviews to collect real testimonies that would enrich the interactive narrative with concrete examples of sustainable practices and greater empathy in the story (see Fig. 7).

As for the first step, the students found the conception phase accessible and easy to conduct due to the adoption of the storyboard technique, which provided a logical and predefined pathway to structure their narratives. The storyboard enabled students to verify the sequence of interactions in each step of their documentary, identifying particular issues before its design in the GreenVerse demonstrator. Furthermore, the value of that second activity was positively perceived, because it offered students an active role in creating educational content, which in turn

Fig. 7 Students playing the role of journalists by collecting evidence through direct interviews with their educators during the in-field exploration session

conferred a sense of responsibility towards the content they created.

During the conception phase, the participants experienced freedom in developing their documentaries by exploring different ways of connecting 360° environments beyond linear storytelling. Using hyperlinks between various 360° environments allowed participants to create narratives that explored the same educational challenge in different geographical or temporal situations, comparing environmental events or phenomena in different cultural and social contexts and measuring their effects and consequences in past or future scenarios. Regarding the Serbian workshop, the use of a paper-prototype allowed the students to spatially visualise and preview the contents of their story, facilitating the process of translating from the idea to the interactive prototype.

That opportunity enabled some groups to generate stories that were not entirely related to real-life environments or the local contexts, which gave them the freedom to extend their story on Sustainability Education even at a global scale.

The students who experimented with paper-prototype activities perceived fewer restrictions in developing their stories because they did not encounter the limitations caused by technological constraints in terms of accessibility, functionality or compatibility related to the use of the digital platform. We detected the difficulty for students in translating a two-dimensional drawing into a 3D spherical environment, because it required high abstraction ability and knowledge of the rules related to perspective representation.

Finally, the immersive experience offered by the GreenVerse Interactive Platform received positive feedback from students. That was because the digital tool allowed participants to enrich their educational documentaries

with explorable and interactive multimedia content that stimulated user engagement. Specifically, the students appreciated the possibility of transforming and conveying the theoretical learning of their narratives through concrete examples, which they had previously collected as evidence in the first phase of the workshop. Because of this, some groups used testimony storytelling to create greater empathy and a relationship between the narrative and its listeners while transmitting the message.

The GreenSCENT platform features also motivated the students to freely create their documentaries without particular constraints that limit their ideas. Specifically, the freedom of connecting different environments with no temporal or spatial constraints was perceived as an excellent value because it allowed some students to highlight the cause-effect relationship of certain environmental behaviours (e.g. representing the life cycle of a given product from its production and use to its disposal), which would otherwise be invisible in the real-world.

The teachers who observed the workshop also expressed positive feedback because they noticed that the students acquired an active role during the documentary development process. After all, the methodology enabled them to carry out both the context exploration and content creation activities in an autonomous and self-managed way.

In terms of accessibility of educational technologies, there were some constraints related to the understandability and usability of the GreenVerse Immersive Platform while conducting the Greek workshop, even though we received a positive evaluation of the demonstrator from the students. Despite the fact that the early version of the platform was able to provide students with some of the most common accessibility features to access the service—such as multilingual access, colour contrast, simple navigation structure, text size settings, or visible hypertext links—other barriers based on different technological resources occurred during the interaction with the demonstrator. For example, the students found uploading their multimedia content on the platform difficult due to the lack of compatibility with the file formats between the mobile devices and the prototype and with the storage space availability of their institution. Another limitation was related to the poor internet speed on the institutional network. These issues produced a delay in the development process of the interactive scenarios and limited the choice of multimedia content. Furthermore, the students needed time to familiarise themselves with the specific functionalities of the demonstrator, which required guidance from researchers to facilitate the interactive documentary development process on it.

In particular, the students faced various challenges in understanding and using the spatial concept provided by the 360° documentary environment because they were not used to representing content in a spherical space. Students evaluated the platform as understandable only in the Serbian panel because the whole process of transforming the two-dimensional contents into 360° scenarios had already been performed in the previous activities with the paper prototypes. In that case, the students utilised the GreenVerse

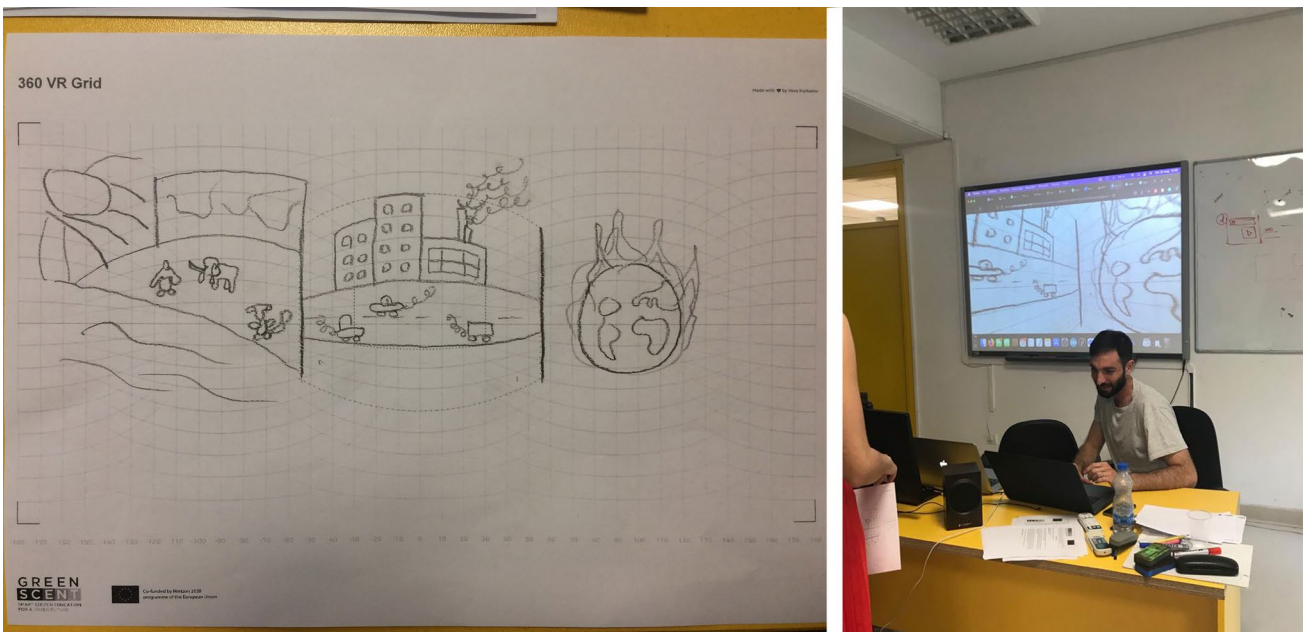

Fig. 8 On the left, the representation of a 360° educational scenario designed with a paper-based template. On the right, the same educational scenario visualised with the GreenVerse Interactive documentary demonstrator

demonstrator only to visualise the content already designed on the paper-based template (see Fig. 8).

6 Discussion

Developing technology-enhanced learning solutions to foster Sustainability Education requires tackling complex and heterogeneous educational challenges among many different socio-cultural European contexts where traditional design techniques no longer seem to have a practical impact on solving those issues. Empowering educational institutions to promote Sustainability Education means not only providing people with knowledge and skills to adopt sustainable behaviours but also stimulating their attitude to sustain an ecological mindset in the long-term perspective without being affected by any particular subjective norm produced by traditional socio-cultural behaviours that may negatively influence their behavioural intention [32, 33], such as driving a car instead of a bicycle because that action is perceived as a normal behaviour in my community.

Considering that, Sustainability Education needs innovative participatory design strategies capable of extending and adapting their practices at different scales of design intervention. In particular, the methods described in the previous paragraph, aim to foster collective creativity among target users and leverage the definition of the strategies and the tools for the acquisition of Sustainability Education competences, promoting pro-environmental behaviours.

In this section the authors discuss the relevant issues in Sustainability Education that arose during the co-design activities about the role of teachers, user engagement, empathy with sustainability goals, technology adoption, the 'making visible' approach.

6.1 Focussing on teachers

Teachers represent the bridge between knowledge and students, and their role is essential in facilitating learning for sustainability. However, as it has been found in our research activities, they have no time for teaching Sustainability Education during their ordinary activities because the topic is not in the official curriculum of the national schools' educational programmes [34]. We noted that only well-motivated educators are willing to adopt integrative or extracurricular teaching activities to dedicate a short time to Sustainability Education.

Competence enhancement. Although Sustainability Education is a complex subject that requires extra learning to enhance appropriate educational competencies, teachers reported that they have encountered many obstacles to implementing their teaching background during the school year. As already observed in the literature [35], educators have difficulty managing the multi-disciplinary aspects of sustainability, so they feel unprepared during the teaching process. In that case, our educational technologies can be designed with the intent of ensuring competence enhancement among teachers by supporting them through pre-designed learning formats—in the form of tutorials, guidelines, or even training kits—which can improve their knowledge acquisition in a reduced period of time.

Easy to learn. Since the co-design experiences highlighted people with a heterogeneous level of tech savviness among teachers and students, educational technology must be adaptable to different levels of digital literacy. Considering that, it is the prerogative of this research study to develop accessible educational technologies that must be easy to understand to encourage its adoption in regular national schools' learning programmes. As for competence enhancement, a training programme for understanding the use of technology can be provided in the form of short instructional videos, tutorials, or educational pillows that facilitate knowledge acquisition among people.

Easy to use. Our instructional modules on Sustainability Education must facilitate the work of the teachers by providing educational technologies and tools that students can utilise autonomously to plan learning activities more efficiently. The digital tools can be implemented with pre-structured resources (pre-sets of data, environments, or multimedia resources) or pre-structured teaching formats (selection of examples, scenarios, or experiments) that can help educators to save time for preparing the lesson or coordinating the class during the educational activity.

6.2 Engagement and learning

Our co-design experiences found that students must be involved in hands-on activities to give them the opportunity to directly experience the values of adopting sustainable behaviours. For this reason, equipping technology with some user-entertainer strategies can help teachers encourage students to take an active role in the activities while creating curiosity and interest in participating.

Learning-by-doing. Educators reported that a learning-by-doing experience is able to raise students' awareness about the consequences of a particular behaviour by making tangible the added benefit of that action while it is performed. That is because practice-based activities clearly show cause-effect evidence of a particular behaviour. In that way, students can raise awareness by experiencing real-life situations that make theoretical learning more memorable and tangible. Moreover, practical activities allow students to interact directly with nature and increase their empathy for the environment.

Long-lasting education. Sustainability Education cannot be limited to a temporal or spatial condition. An effective learning environment must prolong Sustainability Education outside the educational institutions to continue during everyday life. Considering that, designing proper instructional modules that sustain a constant engagement in Sustainability Education can transform practice-based activities into daily habits through an iterative school-home process that can affect not only students' behaviours but also the attitude of their parents. In that case, stimulating a parent–child interaction can help the educational community involve parents in the educational process. That, in turn, would enable the social community to tackle conservatism on sustainable topics.

Gamification. Game strategies can be implemented into technology to make Sustainability Education more engaging and pleasant to learn and experience. Challenge-based education is a virtuous example of increasing sustainability because it enhances collaboration among students and sustains the activities in the long-time perspective turning simple exercises into positive behaviours. In addition, rewards or honours can encourage user engagement because they can offer personal benefits to students (for example, less homework or more good votes) or advantageous social positions (for example, the best sustainable student of the month) that can have a positive social impact inside their institution.

6.3 Make the invisible visible

Technology can raise awareness of sustainability among people by showing the complexity of those phenomena that are often invisible or imperceptible to human senses by adopting immersive and augmented learning experiences. Many techniques and approaches, such as data visualisation, spatial analysis, digital modelling, documentary research, and situated interviews [36, 37], can be adopted simultaneously to make more effective use of technology in education, helping people to understand problems, make decisions, predictions, or measure and assess the impact of a particular action.

Anticipation of actions. Technology can help students to report and visualise the consequences of a particular sustainable choice through the development of digital simulations or even predictions, such as time-lapse imagery [38], which are able to make visible the consequences of a given invisible action along a timeline. That approach can help people to stimulate their critical thinking by correlating a current problem or phenomenon to another in the past to understand the causes and prevent them in a near-future situation [39].

Comparison. Measuring the strengths and weaknesses of particular products or behaviours and comparing each other through a visual explanation can help people to increase their awareness of sustainability by allowing them to ponder their sustainable actions.

Clear explanation. Providing theoretical information with visual and interactive resources and narrations allows people to understand the complexity of a particular phenomenon related to Sustainability Education. For example, transforming scientific literature into an inclusive narration can help educators to spread the message to not-expert people.

First-person experiences. Narrating immersive and augmented learning experiences by using a first-person perspective can help the storytelling to increase emotional connection to a specific problem in Sustainability Education. That setting can be experienced through concrete documentary evidence that reports real-life or real-world examples, which enable people to impersonate themselves in a particular situation and, hence, raise awareness of the related problems by stimulating their empathy.

7 Conclusion

Co-design workshops can create a safe and creative space where students can freely express their concerns, hopes, and expectations, and collaborate towards a shared vision of Sustainability Education. In fact, co-design workshops can enable researchers and designers to understand the needs, preferences, and aspirations of the target audience, and co-create innovative solutions with them towards an enabling condition in which users can act as active and equal idea contributors [40].

Also, co-design participatory activities can help researchers identify the specific challenges and opportunities that arise from the use of new technologies in Sustainability Education to ensure that the new solutions will be not only effective and user-friendly but also socially and environmentally responsible.

As encountered throughout co-design activities, scenarios with limited (or low access to) resources can bring a series of operational obstacles that make those novel technologies unusable. Often, there is a gap between reality and imaginary of adoption of technology. Recent developments in design research have critically discussed the undefendable nature of the cornucopian vision [41], meaning that digital infrastructure is limitless and continued progress is possible and preferable. From this perspective this research advocates for intentionally moderating digital interactions and provide design solutions that span in one ideal continuum from fully digital to hybrid, until low resource scenarios where scarcity is prevailing abundance, and limits rule over desires.

The diversity of excluded communities or environmental conditions of given contexts brings Sustainability Education

to develop sustainable digital experiences that are compatible and scalable according to the level of resources of a particular educational scenario. As we noted, a possible design direction could be to provide the same educational experience whether being characterised by an augmented and immersive experience, or by a low-resolution and off-line application, with a paper-based materials.

This perspective could allow the overall technological service to become more accessible and 'universal' to use even when we must deal with resource-poor contexts.

Acknowledgements The authors wish to thank all the personnel of the three institutions that helped to make the workshops successful: Ellinogermaniki Agogi School in Athens, Greece, Gimnazija Smart School, and University of Novi Sad, in Novi Sad, Serbia, and IES Raspall in Cardedeu, Spain. They offered precious support in organising the co-design sessions in their spaces, involving students, and providing technology and materials for the activities.

Author contributions AP wrote the entire Sect. 1. GAG wrote the entire Sects. 4 and 6, Sects. 5 and 5.2. AP and GAG wrote the entire Sect. 2 jointly. DU and KC wrote the entire Sects. 3 and 7, Sect. 5.1 jointly. D.U. and K.C. prepared Figs. 1–3. AP and GAG prepared Figs. 4–8. All authors reviewed the manuscript.

Funding The GreenSCENT research project has received funding from the European Union's H2020 Framework Programme for SOCIETAL CHALLENGES—Climate action, Environment, Resource Efficiency and Raw Materials under Grant agreement ID. 101036480.

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

Ethical approval The ethical certificate for the GreenSCENT research project was provided on 27 July 2021 by the Comisión de Ética en la Experimentación Animal y Humana (CEEAH) at the Universitat Autònoma de Barcelona under the protocol number CEEAH 5712. Permission to conduct the co-design activities for the purposes of this research was obtained by all respondents, who were fully informed about the purposes of this study and how their data would be used and stored.

Consent to publish statement The authors affirm that human research participants provided informed consent for publishing their data and photographs.

References

1. Development World Commission on Environment and Development: Our common future. Oxford University Press, Oxford (1987)
2. Tomlinson, B., Silberman, M.S., Patterson, D., Pan, Y., Blevis, E.: Collapse informatics. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. pp. 655–664. ACM, New York, NY, USA (2012). https://doi.org/10.1145/2207676.2207770.
3. Remy, C., Huang, E.M.: Limits and sustainable interaction design: obsolescence in a future of collapse and resource scarcity. First Monday. (2015). https://doi.org/10.5210/fm.v20i8.6122
4. Preist, C., Schien, D., Blevis, E.: Understanding and mitigating the effects of device and cloud service design decisions on the environmental footprint of digital infrastructure. In: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. pp. 1324–1337. ACM, New York (2016). https://doi.org/10.1145/2858036.2858378.
5. Papanek, V.: Design for the real World: human ecology and social change. Knopf Publishing Group, New York (1971)
6. Press, M., Cooper, R.: The design experience: the role of design and designers in the 21st century. Ashgate Publishing, Bodmin (2003)
7. Erlhoff, M., Marshall, T.: Design dictionary: perspectives on design terminology. Birkhäuser, Berlin (2008)
8. Margolin, V., Margolin, S.: A "Social Model" of design: issues of practice and research. Des. Issues **18**, 24–30 (2002). https://doi.org/10.1162/074793602320827406
9. Veiga, I., Almendra, R.: Social design principles and practices. In: Lim, Y., Niedderer, K., Redström, J., Stolterman, E., Valtonen, A. (eds.) Design's Big Debates—DRS International Conference 2014, 16–19 June, Umeå, Sweden, pp. 1–12. DRS Digital Library, London (2014)
10. Monteiro, M.: Ruined by design: how designers destroyed the world, and what we can do to fix it. Mule Books, Fresno (2019)
11. Bassi, A.: Design contemporaneo. Istruzioni per l'uso. Il Mulino, Bologna (2017)
12. Moretti, M.: Socio-social-design: design practices for new perspective on migration. Corraini Edizioni, Mantova (2019).
13. Hanks, K., Odom, W., Roedl, D., Blevis, E.: Sustainable millennials. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. pp. 333–342. ACM, New York (2008). https://doi.org/10.1145/1357054.1357111.
14. Mankoff, J.C., Blevis, E., Borning, A., Friedman, B., Fussell, S.R., Hasbrouck, J., Woodruff, A., Sengers, P.: Environmental sustainability and interaction. In: CHI '07 Extended Abstracts on Human Factors in Computing Systems, pp. 2121–2124. ACM, New York (2007). https://doi.org/10.1145/1240866.1240963.
15. Brauer, B., Ebermann, C., Hildebrandt, B., Remane, G., Kolbe, L.: Green by app: the contribution of mobile applications to environmental sustainability. In: Proceedings of 20th Pacific Asia Conference on Information Systems (PACIS 2016). Associaton for Information System Electronic Library, Chiayi, Taiwan (2016).
16. Lindenberg, S., Steg, L.: Encouraging sustainable behavior. Psychology Press, New York (2013). https://doi.org/10.4324/9780203141182.
17. Light, A.: Ecologies of subversion. Interactions **29**, 34–38 (2022). https://doi.org/10.1145/3501301
18. Stembert, N.: Co-creative workshop methodology handbook. U4IoT, Rotterdam (2017).
19. Bodker, S.: Creating conditions for participation: conflicts and resources in systems development. Human-Computer Interact. **11**, 215–236 (1996). https://doi.org/10.1207/s15327051hci1103_2
20. Binder, T., Brandt, E., Halse, J., Foverskov, M., Olander, S., Yndigegn, S.L.: Living the (codesign) Lab. In: Nordes (ed.) he Nordic Design Research Conference 2011 MAKING DESIGN MATTER May 29th – 31st, Helsinki, Finland. pp. 1–10. , Helsinki (2011).
21. Jansen, S., Pieters, M.: The 7 principles of complete co-creation. Bis Publisher, Amsterdam (2017)
22. Lauttamäki, V.: Practical guide for facilitating a futures workshop. Turku School of Economics, Turku (2014). ISBN 978-952-249-297-5.
23. Lazar, J., Feng, J.H., Hochheiser, H.: Research methods in human computer interaction. Morgan Kaufmann Publishers, Cambridge (2017)
24. Thor, D., Karlsudd, P.: Teaching and fostering an active environmental awareness design, validation and planning for

action-oriented environmental education. Sustainability. **12**, 3209 (2020). https://doi.org/10.3390/su12083209
25. Korteling, J.E. (Hans), Paradies, G.L., Sassen-van Meer, J.P.: Cognitive bias and how to improve sustainable decision making. Front. Psychol. **14**, (2023). https://doi.org/10.3389/fpsyg.2023.1129835.
26. Druin, A.: The role of children in the design of new technology. Behav. Inf. Technol. **21**, 1–25 (2002). https://doi.org/10.1080/01449290110108659
27. Ampatzidou, C., Gugerell, K.: Participatory game prototyping—balancing domain content and playability in a serious game design for the energy transition. CoDesign **15**, 345–360 (2019). https://doi.org/10.1080/15710882.2018.1504084
28. Smith, S.M., Ward, T.B., Schumacher, J.S.: Constraining effects of examples in a creative generation task. Mem. Cognit. **21**, 837–845 (1993). https://doi.org/10.3758/BF03202751
29. Bedir Erişti, S.D.: Participatory design based digital storytelling and creativity in elementary school. Turkish Online J. Qual. Inq. **7**, 462 (2016). https://doi.org/10.17569/tojqi.28031.
30. Nebeling, M., Madier, K.: 360proto. In: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. pp. 1–13. ACM, New York- (2019). https://doi.org/10.1145/3290605.3300826.
31. Lee, L.-S., Lin, K.-Y., Guu, Y.-H., Chang, L.-T., Lai, C.-C.: The effect of hands-on 'energy-saving house' learning activities on elementary school students' knowledge, attitudes, and behavior regarding energy saving and carbon-emissions reduction. Environ. Educ. Res. **19**, 620–638 (2013). https://doi.org/10.1080/13504622.2012.727781
32. Ajzen, I.: The theory of planned behaviour: reactions and reflections. Psychol. Health **26**, 1113–1127 (2011). https://doi.org/10.1080/08870446.2011.613995
33. Li, X., Dai, J., Zhu, X., Li, J., He, J., Huang, Y., Liu, X., Shen, Q.: Mechanism of attitude, subjective norms, and perceived behavioral control influence the green development behavior of construction enterprises. Humanit. Soc. Sci. Commun. **10**, 266 (2023). https://doi.org/10.1057/s41599-023-01724-9
34. Grauer, C., Fischer, D., Frank, P.: Time and sustainability: a missing link in formal education curricula. J. Environ. Educ. **53**, 22–41 (2022). https://doi.org/10.1080/00958964.2021.2009429
35. Parry, S., Metzger, E.: Barriers to learning for sustainability: a teacher perspective. Sustain. Earth Rev. **6**, 2 (2023). https://doi.org/10.1186/s42055-022-00050-3
36. Cattabriga, A.: Design tools for alternative narratives. DIID. **1**, 79–93 (2022). https://doi.org/10.30682/diid7521i.
37. Ware, C.: Information visualization: perception for design. Morgan Kaufmann Publishers, Waltham (2019)
38. Buckley, E.M.B., Allen, C.R., Forsberg, M., Farrell, M., Caven, A.J.: Capturing change: the duality of time-lapse imagery to acquire data and depict ecological dynamics. Ecol. Soc. **22**, 1–12 (2017)
39. Nakamura, K.W., Fujiwara, A., Kobayashi, H.H., Saito, K.: Multi-timescale education program for temporal expansion in ecocentric education: using fixed-point time-lapse images for phenology observation. Educ. Sci. **9**, 190 (2019). https://doi.org/10.3390/educsci9030190
40. Trischler, J., Dietrich, T., Rundle-Thiele, S.: Co-design: from expert- to user-driven ideas in public service design. Public Manag. Rev. **21**, 1595–1619 (2019). https://doi.org/10.1080/14719037.2019.1619810
41. Widdicks, K., Remy, C., Bates, O., Friday, A., Hazas, M.: Escaping unsustainable digital interactions: toward "more meaningful" and "moderate" online experiences. Int. J. Hum. Comput. Stud. **165**, 102853 (2022). https://doi.org/10.1016/j.ijhcs.2022.102853