UNIVERSITA' DEGLI STUDI DI CAMERINO

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Educational paths on environmental sustainability in virtual worlds

PhD student **Supervisor**

Michelina Occhioni **Prof. Eleonora Paris**

to Luisa,

my sunshine

“We are increasingly asking if what people learn is truly relevant to their lives, if what they learn helps to ensure the survival of our planet. Education for Sustainable Development can provide the knowledge, awareness and action that empower people to transform themselves and transform societies”.

Stefania Giannini, Assistant Director-General for Education, UNESCO

“It is in us that landscapes have landscape. So if I imagine them, I create them; if I create them, they exist; if they exist, I see them. [...] Life is what we make of it. Journeys are the travelers. What we see is not what we see, but what we are”.

Fernando Pessoa, writer

“And may your eyes be full of adventures, and horizons leading to the sea.
Carry on shining in every season, treasure your steps for a better time”

(“E di avventure sian pieni i tuoi occhi, e di orizzonti che corrono al mare.
Continua a splendere in ogni stagione, conserva i tuoi passi per un tempo migliore.”)

Modena City Ramblers, combat-folk musicians

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ABSTRACT

This research project aims to contribute to introduce 11-14 years old students (i.e. Scuola secondaria di primo grado in Italy) to topics related to sustainability and the environmental impact of human activities in the framework of Agenda 2030 for Sustainable Development. This work represents the first attempt to approach this topic in a comprehensive way by using Virtual World environments, with the idea to attract students' interest as well as vehiculate acquisition of science knowledge and IT competence, in an immersive and stimulating set-up.

Topics as Agenda 2030 Sustainable development goals, climate change, environmental footprint indicators, renewable energy, properties and use of critical minerals, and metal recycling were chosen for this research, as they are strictly connected with students' everyday life (such as rare earth element impact for the production of electronic devices) and therefore useful to attract their attention on sustainability.

This works aims also to support Italian schools in the implementation of the recent and mandatory "Civic and environmental education curriculum" focused on links between legality, sustainability and digital skills. Supporting school teaching took on particular meaning as, within months of the introduction of such curriculum, the Covid-19 pandemic made distance learning essential for continuing educational activities. The activities in this research were formerly planned to take place at a distance accessing 3D virtual worlds in form of avatar, so this research was one of the ways in which the pupils of the schools involved were able to carry out engaging activities in remote, feeling "close" to their classmates.

Seven different activities were designed and planned to be carried out in virtual worlds (VW), using three different 3D digital platforms (Opensimulator, FrameVR, and Minecraft) for 11-14 years old students. In two of the activities, before involving the students, the learning paths were tested by lower and higher secondary school teachers to evaluate their effectiveness and gather suggestions for improving content and modes of use.

The main didactic approaches used were the Game-based learning and the Inquiry-based learning, both typical active learning methods, widely used in virtual worlds. In the first approach, the educational path was set up by the author, to be explored by students. In the second one, students built a path on a specific topic, from the initial idea to the final products, starting from an empty environment or a template scenario. The topic proposed integrate in an interdisciplinary way within the courses of Science, Technology, Math and informatics, but also give the possibility to find interactions with other school subjects (such as English, Italian literature) and give the possibility to introduce other themes related to Agenda 2030 to be developed in the classroom (like climate change, pollution, water availability…).

In this research project, topics were developed in different 3D learning scenarios:

Iron City / recycle: students built a metal recycle plant starting from scratch, following the typical steps of an inquiry-based learning projects. This pilot project aimed also to address the future design / plan of the research and test the response of students on the theme of waste.

Sustainability Hub: a virtual world island based on the platform Opensimulator, where students have an initial approach to sustainability, Agenda 2030, georesources, and environmental footprint indicators. In each thematic zone of the island students deal with scientific contents as well as online games, interactive 3D objects and quizzes, to be solved to allow the access to the following zone.

Sustainable City Game: it is a sort of “game of the Goose” developed in cardboard version by Alessandra Beccaceci and set up in virtual version in the Sustainability Hub. Students, alone or in team deal with quizzes and challenges to move from a conventional city to a sustainable city in a ideal path.

Powerland – F: based on the platform frameVR, it is an island where students have the “mission” to find answers about themes related to the energy transition and the use of critical materials. They consult multimedia presentations and solve online games.

Powerland: is an island where other students are involved in the same activity carried out in Powerland-F nut on the Opensimulator platform. This allows a comparison between the two platforms and draw some comments about their use.

Ecocity: it is a city where students investigate the impact of energy in terms of carbon footprint and suggest systems and solutions to reduce the carbon footprint in a urban context. In the experimentation they worked in teams to build solar panels, wind turbine, solar cell car recharger an so on.

My sustainable city: it is an ideal sustainable city build in the platform Minecraft by different students’ teams, each focusing on a specific aspect of urban sustainability: sustainable buildings, transportation, water and energy saving and so on.

From the analysis of pre- and post-activity questionnaires, the students’ final products and the teachers’ and student’s satisfaction surveys, a high engagement level was evidenced for all students participating the experimentation. Best results in the knowledge acquisition tests emerged from students who individually accessed the various paths in virtual world, with respect to the control group who followed the path without interaction. This testifies that the personal engagement helped the students focus to the scientific contents and promoted interest in the topics presented. Following the results obtained in this research, virtual worlds can be recognized as a valid teaching support both in emergency situations like during the pandemic crisis, and also in normal times, as a support to conventional teaching. The idea to approach sustainability topics was a new challenge but the use of VW allowed also to present “laboratory” experiences in the difficult time of the pandemic, allowing students to face problems and find solutions in a social environment.

The contents of this thesis are summarized below.

In Chapter 1 (Introduction, background and theoretical framework) it is recognized the fundamental role of Education to address sustainability as a catalyst for a broad change in the population. Connections between Agenda 2030, sustainability and geosciences are analyzed, choosing topics to be addressed in this research. The affordance (the latent possibilities for action presented by an artefact, tool or environment”, Stucky, 2009) and the features of virtual world as constructivist platforms to foster collaborative work and active learning are discussed in the context of the theoretical framework about learning approaches mainly used in virtual worlds and useful to address Education for Sustainability.

In Chapter 2 (Materials and Methods) the research design, the work flowchart, the list of the activities and types of assessment are described. The research involved 699 students and 75 teachers. Six schools from North, Center and South of Italy participated to the research. Assessment was based on comparisons between pre-activity and post-activity test and/or between experimental and control groups.

In Chapter 3 (Results) all the activities carried out in the aforementioned islands are described in details, each in a specific section. The chapter includes an overview of the learning scenario, the tasks assigned to the students, the learning setting and the results. The discussion on specific issues of the related activity is reported, leaving the general discussion to Chapter 4. A specific section is devoted to the satisfaction survey of all the activities, grouped together as the questionnaire were identical or similar in all the activities proposed.

In Chapter 4, (Discussion) the main results in the frame of the specific literature are discussed and how the research aims have been achieved is explained.

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(Source: Adapted from http://commons.wikimedia.org/wiki/User:Schwarz7201. CC BY-SA 4.0)

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Source:
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Critical raw materials list for 2011–2017 overlaid on the periodic table of the elements

Source: Rizzo A, Goel S, Luisa Grilli M, Iglesias R, Jaworska L, Lapkovskis V, Novak P, Postolnyi BO, Valerini D. The Critical Raw Materials in Cutting Tools for Machining Applications: A Review. Materials. 2020; 13(6):1377. https://doi.org/10.3390/ma13061377 CC-BY-4.0

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I love you, Luisa.

1. Introduction, background and international framework

The aim of the present research is to explore the use and the efficacy of virtual worlds to teach sustainability and Agenda 2030 topics in the classroom or using distance learning. In the following, the relationships between sustainability and geosciences, and the role of education towards sustainability will be approached highlighting the interdisciplinary connections and the use of virtual worlds as didactic tools to engage young students.

1.1. SUSTAINABILITY AND GEOSCIENCE

The development model of the entire twentieth century, when we had the illusion that our natural resources were endless, has reached a turning point, almost to a point of no return. In 2009, Johan Rockström led a group of 28 internationally renowned scientists to identify the nine processes that regulate the stability and resilience of the Earth system. The scientists proposed quantitative planetary boundaries within which humanity can continue to develop and thrive for generations to come. These boundaries include climate change, biodiversity loss, land-use change, freshwater use, ocean acidification, nitrogen and phosphorus cycles, atmospheric aerosol loading, chemical pollution, and ozone depletion. The planetary boundaries framework is an approach to quantifying the safe operating space for humanity with respect to the Earth system and is based on scientific evidence.

The question is simple: are we living far above our planet's ability to provide enough resources for all? Will we be able to reduce waste? For some time now, environmental sustainability, waste management, decarbonization and renewable energy (Edenhofer et al., 2011) have been considered as the set of solutions that could mitigate climate change and the depletion of natural resources (Ellen MacArthur Foundation, 2013, 2019).

On September 25th, 2015, the UN General Assembly adopted the Agenda 2030 for Sustainable Development, a global program to address Sustainable Development (United Nations, 2015), to be implemented by 2030. These goals have been built on the achievements of the Millennium Development Goals (MDGs) (Chopra & Mason, 2015). MDGs projects started in 2002, aiming to reverse the grinding poverty, hunger and disease affecting billions of people.

However, the path towards sustainability started much further back, in 1987, when the need arose for a new definition of development in relation to the growing degradation of natural resources. So, in "Our Common Future" report (known also as Brundtland report) sustainable development was defined as "development capable of satisfying the needs of the present generations without putting the needs of future generations at risk" (World Commission on Environment and Development, 2017). The 17 Sustainable Development Goals (SDGs), divided into 169 total targets, cover global challenges for Humanity, providing an ambitious and holistic reference framework (Figure 1.1).

The multi-dimensional approach of Agenda SDGs towards eradicating poverty and reaching peace is the greatest global challenge of our time (UN, 2017). In fact, SDGs give a new impetus to our collective development aspirations, covering a wide range of issues such as poverty, hunger, health, education, sustainable energy and cities, sustainable consumption and production, climate change, forests, oceans, and peace. In fact, the aims of the Agenda 2030 are to radically transforming society towards the path of sustainability, seeking new societal models compatible with a more conscious consumption of the finite resources available, and regeneration of waste. In simple terms, the entire concept of Sustainable Development means that we can be sustainable only if we address some important issues involving the economic, environmental, and social fields (Allen et al., 2016). SDGs are all interconnected and addressed in a holistic view, joining together the aforementioned dimensions. The challenge is global, everyone is involved, in order to leave no one behind.

Citizens in the twenty-first century must have the ability to coexist peacefully with the environment. To achieve this, they should have environmental literacy and awareness about the dynamic relationship in which our behavior is constantly affecting and being affected by everything natural and human in the Earth's systems. Over one million school students recently went on strike for climate, inspired by Greta Thunberg (Murphy, 2021) and this demonstrates how much young people are sensitive to the problems our Earth is encountering. A holistic view of the Earth's structure and dynamic processes, the geo-resources, the natural hazards and the impacts of human activities, can increase their awareness regarding the environmental problems of our planet and their effects on people (Vasconcelos & Orion, 2021).

Figure 1.1. *Agenda 2030 Sustainable Development Goals*
(Source: https://www.un.org/sustainabledevelopment/news/communications-material/)

At first glance, Agenda 2030 SDGs' could be judged disconnected from geoscience, that seems under-represented (Stewart & Gill, 2017), but it is the contrary: Gill (2016) stressed the importance and the role of Geology/Earth science in addressing sustainable development and Sustainable Development Goals (SDGs). Among them:

- the food security (SDGs 2 and 3) by preserving agricultural soil;
- the access to clean water (SDG 6);
- the energy transition (SDG 7) highlighting the potentials of renewable energy;
- the sustainable exploitation of resources (SDG 12);
- the climate change (SDG 13) and the mitigation of its effects.

The Sustainable Development Goals (SDGs) are strongly related to the impact of human activities on the environment, but to manage Earth materials and processes, spatial and temporal understanding are required. So, geologists must be actively involved to address sustainability in all aspects of society and research, as stressed by Gill and Bullough (2017) regarding the role of geoscience in achieving all 17 of the SDGs, also about the importance of mineral resources and their exploitation.

1.2. SUSTAINABILITY AND EDUCATION

The Agenda 2030 recognizes the critical role of education as a catalyst for a broader change. Education is itself a goal, SDG4 – Quality Education (Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all). It aims to grant access to education for all, eliminating gender disparities and to improve the poor conditions of schools in developing countries, to train teachers, to promote technical knowledge and the skills needed to promote sustainable development (UNESCO, 2017). In particular the SD target 4.7 gives education a key role to promote a sustainable development and lifestyles (UN, 2015, Ferreira et al., 2007) and states:*" by 2030 ensure all learners acquire knowledge and skills needed to promote sustainable development, including among others through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship, and appreciation of cultural diversity and of culture's contribution to sustainable development".*

As the links between humans and nature relate to the health of our planet, education for Sustainable Development becomes necessary in all school curricula and allows pupils to enhance their knowledge, skills, and abilities to behave in a more sustainable manner (Merritt et al., 2019). Therefore, education for Sustainability may contribute to the real change in the students' minds, through well-planned didactic activities, facilitating the societal transformation process the Agenda 2030 requires.

1.3. SUSTAINABILITY COMPETENCES

In the literature there is some degree of convergence about the key competences in sustainability citizen must have (Bianchi, 2020). The early paper by Wiek et al., (2011) has been a milestone to describe sustainability competences. Based on a literature review Wiek proposed five main competences: systems thinking competence, futures thinking (or anticipatory) competence, values thinking (or normative) competence, strategic thinking (or action-oriented) competence, collaboration (or interpersonal) competence. The subsequent reviews of Brundiers et al. (2020) and Redman and Wiek, (2021) gave an almost complete framework adding other emerging competences such as critical thinking competence, intra-personal competence (or self-awareness competence), implementation, integrated problem-solving competence. The main takeaways from the three analyzed frameworks are presented in Table 1.1.

In Figure 1.2 the integrate framework of competences for advancing sustainability transformation is reported with the eight key competencies in sustainability (five established and the three emerging ones), complemented by disciplinary, general, and other professional competencies.

Wiek et al. (2011) considered "critical thinking" a general competence, important but not exclusive to sustainability education. Differing from Wiek et al. (2011, 2016) and Brundiers et al. (2020), Rieckmann (2012) included critical thinking among the key competences for sustainability. Neither the United Nations Decade of Education for Sustainable Development, nor the Agenda 2030 SDG 4.7 provided any explicit learning objectives for sustainable development (Redman & Wiek, 2021). On the contrary, UNESCO "has articulated how key competencies in sustainability can be utilized to develop educational programming around all seventeen of the SDGs" (UNESCO, 2017).

For our research, the following learning objectives were selected from the UNESCO document (2017) and adapted for the target students, so that at the end of the activity proposed, the learner will be able to:

- recognize current climate change as an anthropogenic phenomenon resulting from increased greenhouse gas emissions, realizing which personal actions can be climate-friendly
- understand how individual lifestyle choices influence resources consumption and comprehend the importance of responsible waste production and management (prevention, reduction, reuse and recycling)
- understand the concepts of degradation and slow regeneration of soil, and the importance of soil as our growing material
- recognize the impact of consumption-related activities, using existing sustainability criteria, such as environmental footprint indicators, including the concept of "virtual water" and the need to reduce the individual water footprint in the daily routines
- evaluate the sustainability of the personal needs particularly in the area of energy, transport, water, waste, increasing awareness about the environmental and social impacts of individual lifestyles
- envision sustainable lifestyles
- know about different energy resources, renewable and non-renewable, and their respective advantages and disadvantages
- know the basic principles of sustainable planning and building

1.4. ITALIAN CIVIC AND ENVIRONMENTAL EDUCATION CURRICULUM

In Italy, the transversal teaching of civic/environmental education in the first and second cycle of education has been introduced as mandatory subject in the school year 2020-2021 (MIUR, 2019), with the aim to raise awareness of responsible citizenship starting from childhood. Constitution, Sustainable Development and Digital Citizenship have been the main themes, approached in a transversal and interdisciplinary perspective, to pursue a plurality of learning objectives and skills not attributable to a single discipline only.

According to Orion (2019), there is a gap between the role of Earth science in education and the low consideration is given to this discipline in most schools. In Italy, for instance, although Earth science is present in the curriculum of Italian schools, the interest towards Geosciences is strongly affected by the academic background of the STEM teachers (Science, Technology, Engineering, Mathematics), mostly in Biology or Math (Realdon et al., 2016) which might undermine their involvement in teaching Geosciences. Therefore, too often Geosciences are neglected or taught as a secondary subject (Orion, 2019), where laboratory and field activities are minimized.

However, working in the frame of the Italian Civic (and Environmental) education curriculum, students aged 6-18 years old have the chance to address the Agenda 2030 topics in a holistic perspective, also linking environment, sustainability and Earth science. This opportunity can be then considered a possibility to introduce Geoscience topics which otherwise would be neglected.

1.5. SUSTAINABILITY AND ICT (INFORMATION & COMMUNICATION TECHNOLOGIES)

One of the main characteristics of the Agenda 2030 goals is that they are designed to be challenged from a global point of view and in a trans-disciplinary way. So, it is important for young students to approach them with a different perspective, going beyond the single subject and contextualizing learning in their everyday life.

Table 1.1. *Definitions of key competences in sustainability*
(Adapted from: UNESCO (2017) (ref. Wiek et. al., (2011); Rieckmann, (2012); de Haan, 2010).

Competences	**Definitions**
Systems thinking competence	The abilities to recognize and understand relationships; to analyze complex systems; to think of how systems are embedded within different domains and different scales; and to deal with uncertainty.
Anticipatory competence	The abilities to understand and evaluate multiple futures - possible, probable and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes.
Normative competence	The abilities to understand and reflect on the norms and values that underlie one's actions; and to negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions.
Strategic competence	The abilities to collectively develop and implement innovative actions that further sustainability at the local level and further afield.
Inter-personal competence (or collaboration competence)	The abilities to learn from others; to understand and respect the needs, perspectives and actions of others (empathy); to understand, relate to and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving.
Critical thinking competence	The ability to question norms, practices and opinions; to reflect on own one's values, perceptions and actions; and to take a position in the sustainability discourse.
Intra-personal competence (or self-awareness competence)	The ability to reflect on one's own role in the local community and (global) society; to continually evaluate and further motivate one's actions; and to deal with one's feelings and desires.
Implementation	The collective ability to realize a planned solution toward a sustainability-informed vision, to monitor and evaluate the realization process, and to address emerging challenges (adjustments), recognizing that sustainability problem-solving is a long-term, iterative process between planning, realization, and evaluation.
Integrated problem-solving competence	The overarching ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution options that promote sustainable development, integrating the abovementioned competences.

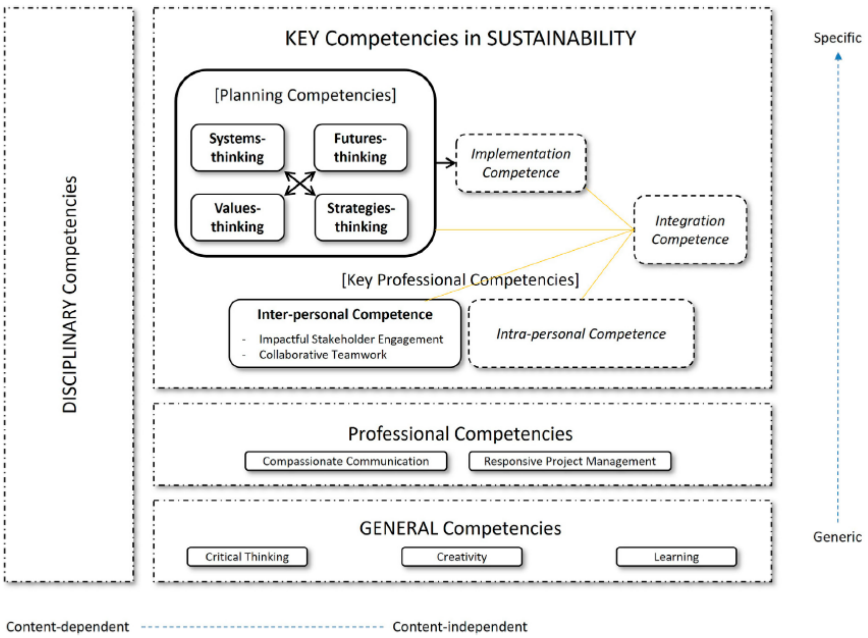

Figure 1.2. *Unified framework of competencies for advancing sustainability transformations; centered on 8 key competencies in sustainability with 5 established (bold) and emerging (italic); and complemented by disciplinary, general, and other professional competencies. Source Redman and Wiek, (2021).*

UNESCO has been promoting Education for Sustainable Development (ESD) since 1992, recommending to plan and run ESD projects (Education for Sustainable Development) in schools and Universities (UNESCO, 2017), and one of the main topics is “Basic skills and competencies needed in the 21st century” (Dede, 2009), which are necessary to support sustainability. Among them there is the Information and Communication Technology (ICT) literacy.

In this framework, in fact, ICT can accelerate and improve the approach to the SDGs through formal, non-formal and informal learning, promoting low-cost e-learning activities. It allows people to collaborate at a distance and facilitate the knowledge transmission, helping to narrow the digital divide between generations and empowering communities. Virtual worlds, as ICT tools, offer a great potential as effective platforms to foster learning (Littleton and Bayne, 2008), allowing in the same virtual environment, a variety of collaborative activities (role play, case studies, reconstruction of possible future scenarios, storytelling) aimed to improve technical and digital skills in addition to the learning of sustainability topics. In section 1.7 a brief excursus on the value of virtual worlds, and the methodological approaches typical of virtual worlds are reported as the premise of the research.

1.6. ACTIVE LEARNING APPROACH / METHODOLOGIES

According to the active learning approach, to create meaning in active learning, students have to produce active effort, doing something (e.g. read, discuss, carry out practical activities) that needs higher-order thinking skills (Cherney, 2011). Technology is a crucial factor in active learning approaches, helping students develop new skills in and through technology. Active learning has its roots in constructivism, that will be discussed in the following section.

1.6.1. Constructivism and Inquiry-based learning

Inquiry Based Learning (IBL) lays its foundations in John Dewey's experiential learning pedagogy (1910) based on discovery. Thanks to the Rocard Report (2007), published by the European Commission, IBL or IBSE (Inquiry Based Science Education) was widely promoted as a valid approach to engage students in active and participatory learning.

IBL is an education approach that focuses on investigation and problem-solving. Respect to the traditional approaches, where teachers present information, students are requested to investigate questions and problem, guided by the teacher. Problems to be posed to students should be preferably those which help students to develop critical and creative thinking, asking questions, designing investigations, interpreting evidence and communicating findings.

IBL is an example of the constructivist method with a student-centered approach to learning, where students are encouraged to have an active role in their educational paths, exploring realistic material, asking questions and sharing ideas (National Research Council, 1996). These methodologies include advantages and constructivist features of “cooperative learning” and “learning by doing”, emphasizing reflection and discussion in every phase. Students try to find answers to their questions through their activities, making decisions, not just following the instructions slavishly. Resources can be found in the classroom, on websites, in libraries, or are first-hand data resulting from laboratory surveys. Teachers ask questions and probe hypotheses to stimulate student discussion and direct reflections (DuVall, 2001). IBL rests on the learning cognitive constructivist theory (Piaget, 1968) according to which knowledge systems of student's cognitive structures are actively constructed pre-existing cognitive structures. In particular knowledge is constructed within social contexts through interactions with a knowledge community (Social Constructivism) (Vygotsky, 1978).

Inquiry-based learning is gaining popularity especially in science teaching due to the recent technical developments that allow the inquiry process to be supported by electronic learning environments (Pedaste et al., 2015) such as virtual worlds.

IBL can be considered a sort of umbrella, a banner that encompass a myriad of conceptual models and approaches (Scott, 2013). Among them problem-based learning and project-based learning are directly related to constructivism and widely adopted in online education (Pearson, 2006).

Another methodology strictly related to IBL is Problem-Based Learning (PBL). It is a student-centered learning approach, in which students use real problems to hypothesize possible solutions. Working together they improve their critical thinking skills, researching and information literacy and problem solving across disciplines (Duch et al., 2001).

Since the early 2000s' it has been noticed that educational virtual worlds allow students to conduct highly interactive, authentic inquiry activities according to the NSES (National Science Education Standards) guidelines. They can observe phenomena and conduct inquiry much as they would in the real world (Nelson and Ketelhut, 2007). Ketelhut et al. (2008) showed that virtual worlds, "when designed around inquiry and science standards, have the potential to engage students in participating in the processes of science, particularly low-achieving students".

1.6.2. Gamification and Game-based learning

In the last 20 years gamification and game-based learning have become complementary methods in education, as various digital tools are available to teachers and students, increasing engagement and motivation (Dreimane, 2019). Although sometimes game-based learning (GBL) and gamification are used as synonyms they are a bit different. GBL can be defined as "learning that is encouraged by the use of a game" (Whitton, 2012), while the gamification approach adapts the mechanics of games to non-games context, such as the educational environment (Deterding et al., 2011).

Games have a positive impact on learning creating a fun learning atmosphere and are a powerful tool for engaging students in science learning and developing their science communication skills (Adipat et al., 2021; Smiderle et al. 2020). In particular, video games can promote active and critical learning, as well as social and cultural participation (Gee, 2003). Whitton (2014) stated that games promote active learning and create motivation; in addition they allow for meaningful play and act as learning technologies.

Then serious games, designed with a primary purpose other than pure entertainment, are explicitly created to educate, train, simulate, or solve real-world problems. Serious games are complete games with defined objectives, rules, and gameplay. They can be computer-based or analog (board games, card games, and so on…) (Abt, 1987).

Applying gamification in education increase motivation in students as long as the gaming elements added to the educational path (rewards, leaderboards, badge, game levels, goals, choices, challenge competitions, customization and so on…) are the translation of learning objectives and reflect the type of player (achiever, explorer, socializer, killer/disruptor, builder/creator, and philanthropist). In addition the aesthetic of the game (visual graphics, auditory elements, the narrative…) should maintain high engagement and motivation to continue learning (Christopoulos & Mystakidis, 2023)

Digital games, including virtual environments, offer a wide range of multiplayer interaction such as teamwork to reach common objectives or just social interaction. Escape rooms (immersive games where players have to solve puzzles and clues within a limited time to escape a themed scenario), challenges, role play can foster learning, improving also transversal skills such as critical thinking (Veldkamp et al.,2020).

In a systematic review, Pellas and Mystakidis (2020) highlighted the potential of the game-based learning approach using virtual worlds (VW), 3D computer simulated environments where users in the form of avatars can interact together at the same time (see paragraph 1.7). A high number of works attested that the use of GBL in VW "can increase students' learning motivation and improve the quality of learning experience for various reasons" such as better spatial knowledge (Twining, 2009), rich 3D scenarios to place games (Barab et al., 2012), and STEM simulations (August et al., 2016).

1.7. VIRTUAL WORLDS

According to the Girvan review (2018), the most cited definition of virtual world is the one Bell (2008) suggested: "a synchronous, persistent network of people, represented as avatars, facilitated by networked computer". According to Girvan, this is quite a techno-centric definition respect the Schroeder's (2008) definition more centered on the user experience: "VW are "persistent virtual environments in which people experience others as being there with them - and where they can interact with them". Girvan himself proposed a more complete definition: Virtual worlds (VW) are "shared, simulated spaces which are inhabited and shaped by their inhabitants who are represented as avatars. These avatars mediate our experience of this space as we move, interact with objects and interact with others, with whom we construct a shared understanding of the world at that time". The avatar is the digital representation of the user (Bailenson et al., 2008).

Virtual worlds are often labeled as MUVE (multi-user virtual environments), "any computer-generated physical space that can be experienced by many people at once" (Castronova, 2005). The simultaneous presence of numerous users is the base for social interactions in learning. Differently from multiuser video games, actions and interactions in the worlds are not planned by a game master, there are no rules, no missions to accomplish, in other words they lack the game grammar (Gee, 2003). Virtual environments are built and shaped by their inhabitants-avatars. Of course, it is possible to add game characteristics to virtual worlds, but in general they can be considered a blank sheet where draw all imagination inspire. The only limit is the user's fantasy.

VW are persistent (Bell, 2008), so they exist even if no users are logged in. In this way, if an avatar, or a group of avatars build something in the world, modifying the scenario, these changes are not temporary but can be seen by other user in real time or asynchronously.

1.7.1. Virtual worlds and education

In a review work spanning about 20 years, Dalgarno and Lee (2010) identified a set of unique characteristics of virtual learning environments (VLEs) that can facilitate learning, particularly spatial knowledge, situated and experiential learning, increased motivation and effective collaboration learning. According to Wilson (1996) a constructivist environment is "a place where learners may work together and support each other as they use a variety of tools and information resources in their guided pursuit of learning goals and problem-solving activities", which is what Dede (1995) illustrated as a virtual world.

Jonassen (1999) defined a set of principles for the design of constructivist learning environments that facilitate the construction of knowledge, according to social constructivist views:

- the learning environment must be focused on a relevant and engaging problem to be solved by the learner.
- the teacher acts as a coach, preparing cognitive tools, also technology-enhanced, providing a space rich in easy and accessible information and communication/collaboration tools.
- students can select information, interpreting the multiple perspectives of the problem and searching for solutions,
- teachers must provide an alternative assessment, analyzing their strategies to solve it.

Dickey (2005) emphasized the role of 3D virtual worlds in providing "experiential" and "situated" learning. Clark and Maher (2005) highlighted how virtual environments encourage "collaboration and constructivism". So, a virtual world "can be considered a constructivist platform based on the learning theories expressed by Piaget (1936) and, later, in the socio-constructivism of Vygotsky (1978), offering many opportunities for teaching and learning (Gül et.al., 2012).

The main features, that give to VW a great potential in education, are their unique features.

- Embodiment (avatar)
- Exploration and navigation
- Communication between users/ avatar synchronous and asynchronous
- Interactivity
- Immersion
- Sense of presence
- Simulation

These features will be explained in detail in this thesis, in separate sections related to the single platform used:

- Opensimulator (opensimulator.org)
- Minecraft (minecraft.net)
- FrameVR (framevr.io)

In table 1.2 the main technical features of the virtual worlds chosen for the experimentation are summarized together with their utility in. At the time of writing, Frame VR, respect to Minecraft and Opensimulator, lacks the possibility to trigger events clicking on objects (except for links to website and browsing multimedia presentation), so it is more suitable for exhibition rather than building and coding activities.

1.7.2. Experiencing a virtual world

According to the literature, there are two different ways to experience virtual worlds (Allison & Miller, 2012):

- learning paths, content and scenarios are set by the teacher, eventually to be reused with different cohorts of students. Exploring and GBL are the best approach in this case (Getchell et al. 2010; Pellas & Mystakidis, 2020).

or

- scenarios are completely planned and set by students, from the initial idea to the final product, under the supervision of the teacher. Generally, an IBL / PBL approach is used (Papamichail et al., 2009; Parson & Bignell, 2011)

In the first case students are users of the world, with a more or less interactivity, in the second case they are active contributors.

It is also possible to approach to virtual worlds in a sort of blended method:

- Educational scenarios are initially developed and built by the teacher, then students add content, new objects, and new paths.

In this research project all the aforementioned approaches were used.

Table 1.2. *Main features of the platforms used for the research*

Function	Tool	Educational use	Opensimulator	Minecraft	FrameVR
Synchronous and asynchronous communication	Text chat Voice	Brainstorming Meetings	✓ ✓	✓ ✗	✓ ✓
3D Modeling	Building modeling terrain	Learning environments 3D learning objects	✓	✓	✓
Coding	Interactive panels 3D learning objects Digital blackboard	Multimedia presentations and videos Quizzes Links to web external resources 3D visualizations of concepts Gamification of educational paths	✓	✓	✗
Photography	Camera Photo tools	Annotation, Lessons	✓	✓	✗
Movements	Walking, running, flying Animations, gestures	Exploring Consulting material Role playing Storytelling	✓	✓	✓
Avatar Customization	Appearance	Avatar clothes, accessories and costumes for roleplay and storytelling	✓	✓	✓
Storage	Inventory	Repository of objects, scripts, textures, animation, annotation, body parts	✓	✓	✓
Travel	Teleport and Hypergrid teleport	Moving from a scenario to another, also in different virtual worlds	✓	✓	✓

1.7.3. Opensimulator

One of the most popular virtual worlds is Second Life, born in 2003 and owned by Linden Lab (secondlife.com). In Second life, avatars can explore the world, meet other residents, socialize, participate in both individual and group activities, build, create, shop, and trade virtual property and services with each other (Rymaszewski et al., 2007). At the end of 2022 Second Life reached about 67 million of users, with an average median daily concurrency of 36000 to 41000. (https://danielvoyager.wordpress.com/).

Since Second Life became a global phenomenon, researchers have been exploring the potential of virtual worlds for teaching purposes (Eschenbrenner et al. 2008) as a distance learning tool, (Inman et al., 2010; Instructor et al., 2007), or in the computer lab, also for science teaching (Fang et al., 2010; Lansiquot et al., 2012).

Opensimulator, (Opensim for short), an "open-source multi-platform, multi-user 3D application server" was born in 2007, when the creators od Second Life decided to release the code of the messaging protocol, to allow an open construction of virtual worlds (http://opensimulator.org).

Although Second Life was pioneering by using virtual worlds for learning purposes, it was not designed for education, especially with underage students. Some problems are related to costs, age restrictions, adult contents. In fact, in 2012, based on reviewed literature, Duncan, Miller and Jiang found that educational projects in Second Life focused on students from high schools and university, rather than school pupils. On the contrary, OpenSimulator can be totally managed in a personal server, with less costs, more control on user access and high customization of the technical parameters (Allison and Miller, 2012). Opensimulator and Second Life share the same communication protocol and can be accessed using the same type of app, a graphical user interface called viewer, such as Firestorm (firestormviewer.org). Different versions for OpenSim and Second life are now available to better manage some particular features of each world (https://www.firestormviewer.org/choose-your-platform/). In other words, Opensimulator (or Opensim for short) can be considered the open-source counterpart of Second life.

The potential of Opensimulator has been explored by many researchers for educational purposes for collaboration, simulation, gamification approaches and experimentation (Allison et al., 2012; Gregory et al., 2016).

Opensimulator allows the creation of constructivist scenarios that follow the Wilson definition (1996) and the Jonassen principles (1999). From a technical point of view, in fact, the Opensimulator-based virtual worlds viewers include the tools needed to work together and collaborate with a sense of presence and students' collaboration and social inclusiveness (Contreras et al., 2018). They include:

- Avatars can move, fly, swim and can instantly "teleport" in different environments called "islands". So, avatars can explore educational path as a sort of 3D web, consulting material at own pace.
- Synchronous and asynchronous communication, in text chat or voice communication, are important to share ideas, to plan and divide jobs, to schedule meetings about the state of the art of the project.
- Multimedia presentations can be shown on panels for meeting and conferences. Slides are imported in the worlds as images.
- Building tools embedded in the viewer allow students to build in a fast and easy way starting from a primitive shape or "prim". A lot of resources (objects, textures, animation, visual effects) can be found in specialized websites and in-world, also by traveling between different virtual worlds (hypergrid protocol, http://opensimulator.org/wiki/Hypergrid). Objects can also be made with desktop 3D modeling applications, such as Blender, an open-source software (http://www.blender.org), and then imported in-world as a COLLADA files (COLLAborative Design Activity).
- Objects can become interactive by inserting into them scripts that give objects behavior (movement, color, transparency, size…) and act as learning objects or "mindtools" (Jonassen, 2000). The tool for text scripting, called Linden Scripting Language or LSL (http://wiki.secondlife.com/wiki/Portale_LSL), is included in the viewer. Alternatively, an external visual block language can be used to avoid syntax errors and facilitate the work as

FS2LSL (http://inworks.ucdenver.edu/jkb/fs2lsl/release/FS2LSL.html) and Scratch4Sl (https://en.scratch-wiki.info/wiki/Scratch_for_Second_Life).

- A Camera Photo tool includes a set of parameters to take photos, modify light, sky and water appearance, move and rotate the camera view, smooth camera movements and so on. Used with an external PC screen capture application it is possible to record video (machinima technique or screen casting).
- Avatars can be provided by animations and gestures to play specified actions used in role play, to act in a story, to express emotions by facial expressions. So, students, with the mediation of avatars can express all their creativity by digital storytelling, through which the pupils become active protagonists of the project.
- Avatars have an inventory in which to store objects, notecards, scripts, landmark, clothes, animations that are sharable with each other.

Perspectives on the effectiveness of these platforms can be found in various fields of educational applications and for different students' age range (Hew and Cheung, 2010; Gregory et. al., 2016). Virtual worlds have been also used for laboratory simulations (e.g. Callaghan et al., 2013; Keeney-Kennicutt & Merchant, 2013). Many educational institutions worldwide run their own Opensimulator-virtual world such as "Science Circle" a multinational alliance of scientists, educators, students and science enthusiasts collaborating to share knowledge and promote open-source education around the world" (www.sciencecircle.org/sc-opensim/) and the University of St. Andrews (openvirtualworlds.org).

In Italy, since the beginning of the 2010s', good examples of best practices of Opensimulator-based virtual worlds for educational activities have been developed (Table 1.3). The EdMondo platform by Indire (National Institute for Documentation, Innovation and Educational Research, by the Italian Ministry of Education) is devoted to continuing education for in-service Italian teachers and projects with their students in humanistic, language and scientific fields (Benassi and Cinganotto, 2015). The platform Techland was created and widely tested for STEM teaching (Occhioni, 2017; Occhioni & Paris, 2021). The University of Camerino (Unicamearth, Geoscience Education Group) created a series of activities related to geosciences (Boniello & Paris, 2016; Paris et al., 2020); "Craft-world" is a public virtual world for a community of teachers and artists (e.g. Tricarico, 2021).

Table 1.3. *List of educational Opensimulator virtual worlds which host Italian teacher communities*

Name	Referent	Focus	Notes
Techland www.virtualscience.it University of Camerino, Italy	M. Occhioni	STEM and Sustainability	Techland hosts both areas that can be visited from other virtual worlds and controlled access zones.
UnicamEarth d7.unicam.it/unicamearthisland/ University of Camerino, Italy	A. Boniello, E. Paris	Geosciences	Controlled access virtual world
Edmondo http://edmondo.indire.it/ Indire (National Institute for Documentation, Innovation and Educational Research, Italy	A. Benassi	Scientific, artistic and liberal art projects	Controlled access virtual world reserved to in-service Italian teachers and students
Craft World www.craft-world.org	R. Macis	Education, Art, Entertainment	Public international virtual world providing for rent customized and protected environments for teachers and students

According to Marino (2004) the word Machinima (screen capture in virtual worlds) is the merge of the words machine and cinema. He defined a machinima a sort of "marriage of mediums; a mixture of the creative platforms, filmmaking, animation and 3D game technology". So, machinima is a special film technique that allows the creation of stories taking place in virtual worlds and in video game scenarios. Video are created by the PC screen capture, using specialized application and video editor suites**.** Machinima video started to be used in 1993, when the developers of the multi-player game Doom released it with a feature that allowed to record, and reproduce later, game actions. In that case, they were demo files that required the original game to view them. Instead, the first real machinima product delivered as video format was Quad God, a 2000 film made by Tritin Films (Kelland, et al., 2005).

Year by year machinima videos became popular among gamer communities to share game strategies and instructions. The most popular games used in machinima technique are World of Warcraft and the Halo games**.** Virtual worlds, such as Second life and Opensim-based worlds, unlike World of Warcraft and other videogames, have the unique features that scenarios can be built by the users, so it possible to customize environments and avatar apparel to the need of the stories. The user acts as a puppeteer of the avatar (Lowood, 2006), via the user interface (viewer) imparting animation and gestures.

Especially in Second life lot of artists have been inspired not only to represent virtual daily life, but every genre from drama, documentary, romance, music video, news, sports and so one. Machinima technique meet the innate desire to tell stories used both by amateur and by professional and permits low cost production (Johnson and Pettit, 2012). Screencasts have become extremely popular in virtual learning environments and in PC users due to their simplicity and effectiveness in explaining 'how to' situations, such applications instructions, task performed inworld and so one. During the process the game engine acts like a virtual film studio with tools as lighting, staging, and camerawork. It is possible to produce real time performances, recorded game sessions, or post-produced linear video clips. Thanks to ever increasing improvements of the real time 3D game engines, in the last years it is possible to find on YouTube channels lots of screencast videos and machinima stories.

So, educators and archivists have begun to experiment this affordable way of expression recreating history and engaging audiences through reenactments and role play. Therefore, machinima became also the best way among educator to display the potential of virtual worlds in education ranging from history reconstructions, literature and scientific subjects. While virtual worlds have its potential in synchronous interactions, Machinima can extend the occasions of learning in an asynchronous way (Kirriemuir 2007). Using some YouTube tools students can create interactive educational machinima products and branching videos (Snelson, 2011).

Teacher can take advantage from screen capture to record dynamic interactions between students/avatars and navigations of the environment. Coupled with the cooperative learning and the IBL methodology, the machinima technique allows students to document projects, tackle scientific topics in a more motivating way and constitute the digital artefact that can be used for the evaluation of the inquiry cycle. Machinima are natural substrate for working in group, collaborate at distance and share jobs. Gregory et al. (2011) highlighted that virtual worlds and machinima actively also allow changing the perspective of teaching practice and curricula such as business scenarios and virtual excursions, role-play simulations, experimentation and language development.

In this research project, screen casting videos were made by students as final products to explain their work.

1.7.4. Minecraft

Minecraft is an open-ended sandbox videogame, a multi-user virtual world where users can shape the land and craft objects using square blocks. Since its birth, it had a worldwide success among children and teenagers but not only. Although Minecraft, as other games and VW, was not designed specifically for educational purposes, it is wide used in education (Nebel et al., 2016) because allows collaborative work, the improvement of digital skills, and creativity. Students can show in a tangible way the comprehension of the topics proposed (Cipollone et al., 2014). In fact, an educational version (Minecraft Education Edition MEE, now Minecraft Education) was released in 2016 specifically designed for classroom use and to better meet the teachers' needs (Kuhn, 2018). The methodology used can be encompassed in the framework of constructionism and connected learning (Niemeyer and Gerber, 2015).

Using Minecraft, it is possible to foster learning using new tools that students view as entertainment. In a review paper, Alawajee (2021) examined contemporary research on the use of Minecraft for educational purposes, to find whether Minecraft can be efficiently and beneficially utilised in educational setting. The paper concludes stating that "most of the included articles illustrate how Minecraft can be a useful tool for educational use and social and communication learning if used effectively with well-designed lessons".

1.7.5. Web based Virtual Worlds (FrameVR)

Web based virtual worlds are immersive online space, reachable directly from the web browser, simply typing a link, suitable to collaborate with other people, for meetings, training or exhibitions. Among them there are FrameVR (framevr.io), spatial (spatial.io) and Mozilla Hubs (hubs.mozilla.com/). Until now these worlds have less interaction with objects capabilities respect to Opensimulator and Minecraft, but are easier to use (Gómez et al., 2021; Cleto et al., 2022) and can be experienced with virtual reality headsets, mobile devices and PC (Ha et al. 2022). Their main use is for social hanging, meeting and art and scientific exhibits (Asino et al., 2022). Frame VR allows the creations of 3D immersive space, starting from an empty space, library environment template or a PC custom environment. First-person customizable avatars (android shaped or human shaped) can communicate in real time with text chat and voice, use webcam, share screen and so one. Various assets can be added to the environment:

- Images
- Browsable multimedia presentations (in pdf format)
- Videos
- 360 photos
- 360 videos
- Audios
- Texts
- Shapes (spheres, cubes, pyramids…)
- 3D models (from PC or sketchfab.com)
- Polls
- Voice zone (breakout rooms)
- Whiteboard
- Web browser
- Streaming screens
- Entire environments

Web based virtual worlds will become more and more used in education for their ease to use and basic device requirements.

1.7.6. Geoscience in virtual worlds

Worldwide, examples of applications of VW in geosciences or sustainability, besides the research projects carried out by the Unicamearth group at University of Camerino (Italy) (Boniello & Paris, 2016) and Techland (Occhioni, 2017, 2021), are scarce but show the usefulness of this approach for geoscience education. Among them, Lansiquot et al. (2014) experimented a Geoscience module In Second Life focused on mountain weather and sea breeze patterns; Hatzilygeroudis et al. (2013) set up five main learning topics about renewable energy (Solar, Water, Wind, Geothermal, and Biomass); Thorne and Macgregor (2018) dealt with Etopia Island Community in Second life, on topics about Sustainability.

1.7.7. Virtual worlds, Covid-19 pandemic and distance learning

In the same scholastic year of the Italian Environmental and Civic Curriculum's adoption, the COVID-19 pandemic forced most of the Italian schools to adopt distance-learning mode, So, some classes were totally in remote learning, some classes in persons and others in a blended mode, depending on different regional restrictions. Therefore, in exceptional situations such as the COVID-19 pandemic, distance learning has been highly relevant, and determinant for education and the completion of the scholastic year, although it struggled to create an environment conducive to student-centric learning.

Schools were not prepared, but had the need to face with the forced distance learning: they had to set up online learning platforms, use share screen and collaborative work tools and adopt virtual classrooms to continue their educational mission.

At the same time, one of the main challenge schools faced is to preserve human interactions, students-students and teachers-students, in spite of the general context full of uncertainties and fears due to the severe conditions of the pandemic, especially in Italy at that time.

The major challenge of distance learning is, moreover, the capacity of engaging students, avoiding the simple digitalization of a traditional lecture. Ranieri (2021) stated that, during the COVID-19 lockdowns, Italian teachers "kept on applying their usual pedagogy and books", not adjusting the teaching mode to the new forced situation. In fact, the Italian National Institute for Documentation, Innovation and Educational Research (INDIRE, 2020) in a preliminary report highlighted that "videoconferencing lessons were the most widely pursued activities in each school level (89.7% K1-K5 teachers, 96.7% K6-K8 teachers, and 95.8% K9-K12 teachers). Therefore, by then it was evident how there was a strong need to make available to teachers some possible activities to approach the new themes of Environmental and Civic Education, including practical activities and the use of digital tools.

The use of virtual environments can partially overcome the need to combine distance learning with engaging activities, allowing teachers to set up synchronous collaborative activities and group communication with a sense of presence (Contreras-Mendleta, 2018). The rising need of such virtual environments gives a good opportunity for the development of different topics regarding sustainability and Agenda 2030, of particular interest for the teachers of students in these age range. Virtual Worlds (VW) bring students beyond the wall of the classroom in an environment closer to videogames, very familiar to them (Díaz, 2020), where they can collaborate and interact (Girvan, 2018). VW could help teachers to set up learning environments that go beyond the simple videoconference, providing authentic learning. VW give also students the chance to interact with other students in the lockdown periods, while carrying out school activities.

1.8. AIM AND OBJECTIVES OF THE RESEARCH

The general aim of this research is to support schools in the implementation of the civic and environmental curriculum, carrying out engaging activities about sustainability in general, with a special focus on energy transition, critical minerals and their recycle.

The educational activity presented here was planned to help students to approach the basic concepts of environmental sustainability in distance learning using virtual worlds. The activity has been organized taking into consideration the need to:

- offering a choice of topics linking Geosciences and Sustainability, in agreement with Italian school curricula for students of 11-14 years old, with contents easily adaptable to students of other countries (a translation into English is in progress) and to older students (14 to 16 years old)
- carrying out laboratory experiences in distance-learning during the Covid-19 pandemic, but useful also as a teaching aid at school
- providing a scholastic assessment of the knowledge and competences acquired, required by the teachers after carrying out the activities in the VW.

As a math and science teacher in K6-K8 degree schools (Scuola secondaria di primo grado, 11-14 years old students in the Italian system), and passionate of technology and virtual words, my personal goals is to develop engaging activities to enhance students' interest towards sustainability while improving technical and digital skills.

In the frame of a wider research project carried out at University of Camerino on Geoscience Education, we decided to test the utilization of a series of VW on different platforms, mainly devoted to K6-K10 students (age range 11-14 years old), that can access the world from home. These VWs were made available to 6 Italian Middle schools, for a large test of the implemented curriculum on Civic and Environmental Education, which started during the long COVID-19 lockdown periods. The project was devoted to approach the themes of sustainability, especially those most linked to georesources and energy, giving also the possibility to carry out practical activities despite schools' closure due to the pandemic.

This PhD research aimed to investigate virtual teaching methods which could be interactive, stimulating the students in a more engaging way than online screen-sharing of contents and to test the possibility to use virtual worlds as laboratory experience.

2. Materials and methods

2.1. RESEARCH DESIGN

For the implementation of the educational path in the various VW the ADDIE model for instructional design has been used (Aldoobie, 2015). ADDIE stands for Analyze, Design, Develop, Implement, Evaluate. In Figure 2.1. the key activities of the research in the framework of the ADDIE model are displayed.

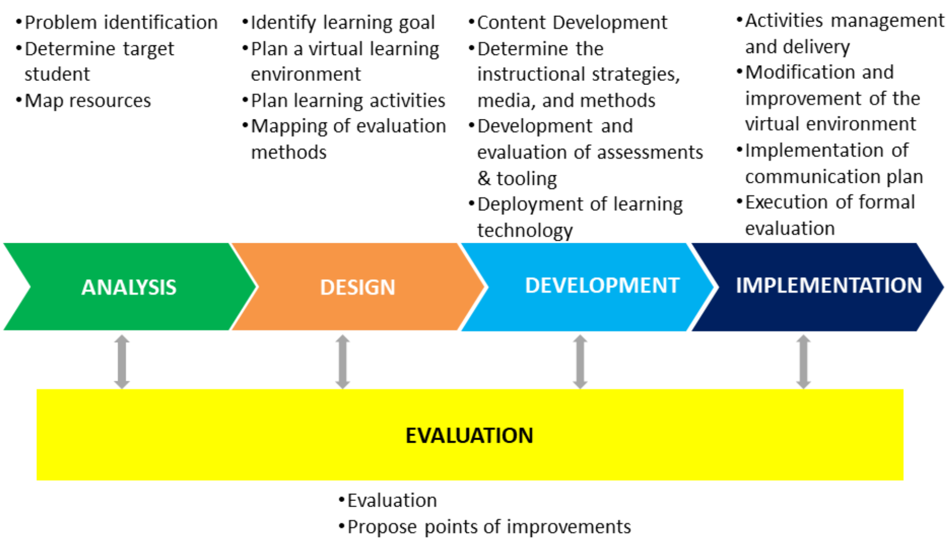

Figure. 2.1. *The ADDIE model of the research. Adapted from http://commons.wikimedia.org/wiki/User:Schwarz7201. CC BY-SA 4.0*

2.2. RESEARCH QUESTIONS

Regarding the use of virtual world in this project, the following research questions, investigated during the experimentation, are addressed:

RQ1: Can virtual worlds be effective in acquiring sustainability knowledge by linking geoscience topics interdisciplinary to other topics?

RQ2: Can virtual worlds help to implement engaging distance learning?

RQ3: Can virtual worlds be a substrate for the aggregation of different digital and transversal skills?

2.3. OVERVIEW OF THE RESEARCH

As previously mentioned in Chapter 1 the research consists of experimenting with virtual worlds to teach sustainability topics. The choice to use VW is also related to the Covid-19 pandemic: WV offer the opportunity to perform remote activities in an engaging way, allowing the implementation of interactive practical activities with a high grade of flexibility. In Chapter 1 the main feature of VW and the typical learning approaches used (GBL and IBL) have been described.

The research plan consists of seven different activities, four according to the GBL approach and three according to the IBL approach, using three different 3D platforms. Activities were labeled as A1, A2a, A2b, A3, A4, A5, A6, each one described in detail in the relative section A1… A6 of Chapter 3.

In Table 2.1 the list of all activities carried out is displayed, showing the main topics and the platform used. A detailed table is reported at the beginning of Chapter 3, as an overview of the entire research.

Table 2.1. *List of the activities experimented in this work (summary)*

Code	Activity name	Topics	3D platform
A1	Recycle/ Iron City	Circular Economy & waste management of metals	Opensimulator
A2a	Sustainability Hub	General approach to sustainability	Opensimulator
A2b	Sustainable City Game	Agenda 2030	Opensimulator
A3	Powerland – F	Minerals for Energy and Technology	FrameVR
A4	Powerland (*)	Minerals for Energy and Technology	Opensimulator
A5	Ecocity	Urban solutions to reduce carbon footprint	Opensimulator
A6	My Sustainable City	The role of cities in sustainability	Minecraft

(*) Activities A3 and A4 are identical in content and students' questionnaires. They differ only in the 3D platform used

Activities A1, A2, and A6 (Table 2.2) have been conducted remotely, due to COVID-19 pandemic restrictions, so students accessed from home. In the activities A3, A4 and A5 students participate from the classroom. In all the activities our research group was always connected remotely.

2.4. DESCRIPTION OF THE LEARNING SCENARIOS

As mentioned in Chapter 1, three virtual worlds platforms have been used to carry out this research: Opensimulator, Minecraft and FrameVR. All activities implemented with the Opensimulator platform have been carried out in the virtual world Techland, owned and managed by me since 2010 and used with my K6-K8 students to perform STEM (Science, Technology, Engineering and Mathematics) activities. In fact, Techland is an archipelago of islands, each devoted to a specific scientific subject. The main activities implemented in Techland are described in various publications (Occhioni, 2013; Occhioni, 2015; Occhioni, 2017; Occhioni, 2018). In Annex 2.1, instructions to visit Techland are displayed.

For my PhD research a new section called "Sustainability" (Occhioni & Paris, 2021) was added, to develop educational and transdisciplinary paths about sustainability. The "Sustainability Section '' encompasses the following islands: Sustainability Hub, Ecocity, Recycle, and Powerland. This section includes also other geoscience resources already developed in Techland (Earthland and Waterland) by me and a copy of the Unicamearth virtual world developed by Annalisa Boniello (Boniello & Paris, 2016) that include paths such rocks and minerals, volcanoes, plate tectonics and earthquakes that help to give more context to a global view of the Earth dynamics (Paris et al., 2021) (Figure 2.2):

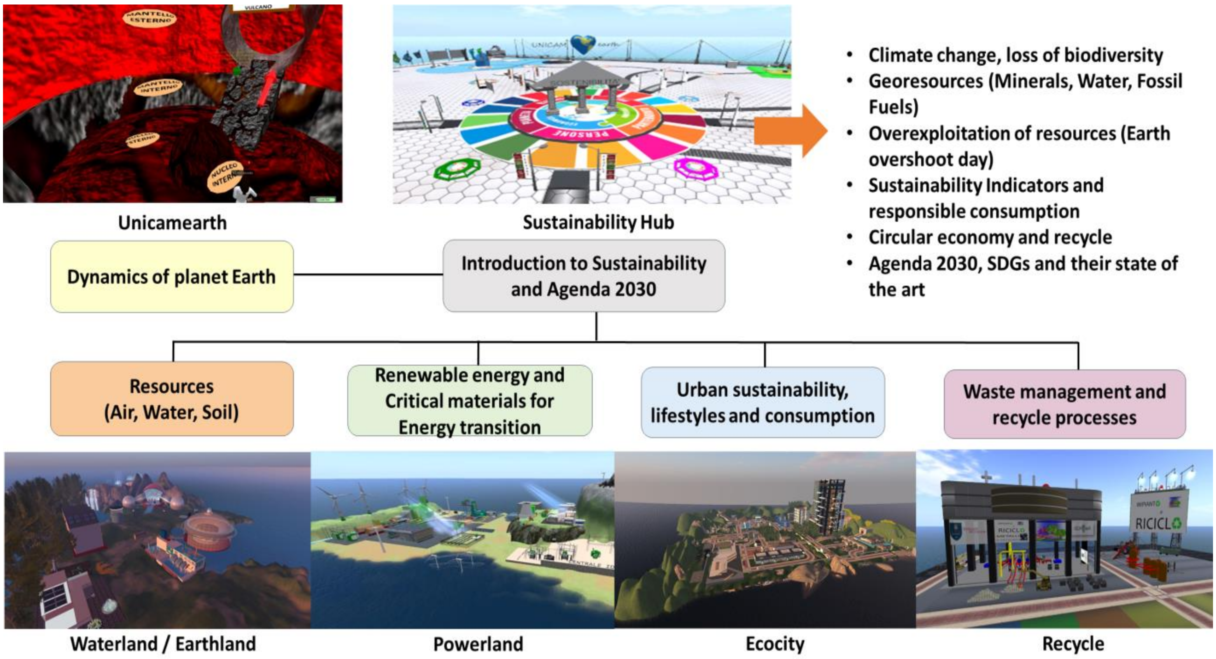

Figure 2.2. *The sustainability section of Techland*

The activity in the Minecraft Education platform was carried out thanks to the INDIRE experimentation *Mineclass* (see Chapter 3 section A6). The activity in the FrameVR platform has been implemented by simply uploading one of the native template scenarios listed in the FrameVR platform (framevr.io), and adding content and 3D models.

In the sections devoted to each activity in Chapter 3, the scenarios will be discussed in detail, therefore they will not be described here, except for the general organization of the experimentation and the data collection and evaluation.

2.5. STUDY POPULATION AND SETTING

Before starting the experimentation with teachers and students, three webinars were carried out in the framework of national events, to present the work plan to teachers and relative students participating in the experimentation.

The entire experimentation included 58 teachers directly involved in the phase 1 of the activity A2a (see Chapter 3, section A2a) and 699 students. Other 17 teachers were involved in the student's monitoring (Activity A2a, A3). The teacher study population is described in Chapter 3, section A2a. In Table 2.2 there is a list of all the schools involved. Details on students' study population (e.g. students' number, grade and gender for each activity) are reported in Chapter 3, in every section from A1 to A6, each devoted to a specific activity. The sum of the students in each activity is higher than the sum of the students in each school, because some students took part in more than one activity.

Table 2.2: *Schools involved in the experimentation.*

School Name	City, Region	Students' grade	# of students	School Code
Istituto Comprensivo Cremona 1	Cremona, Lombardia	K6-K8 (11-14 years old)	77	C
Istituto Comprensivo Soprani	Castelfidardo, Marche	K7 (13 years old)	107	D
Istituto Comprensivo Foscolo-Gabelli	Foggia, Puglia	K6-K8 (11-14 years old)	414	F
Istituto Comprensivo Nettuno 1	Nettuno, Lazio	K7-K8 (12-14 years old)	68	N
Istituto Comprensivo "E. Mestica"	Cingoli, Marche	K6 (11-12 years old)	14	L
Istituto Comprensivo "De Magistris"	Caldarola, Marche	K6 (11-12 years old)	19	K
		TOTAL	**699**	

From now on, the schools will be labeled with their school code. The number of students involved in each activity is reported in sections A1-A6 of Chapter 3. The sum of students involved in each activity is greater than 699, because groups of students were involved in more than one activity.

2.6. RESEARCH WORKFLOW

In Figure 2.3, the flow chart of the research structure is reported, highlighting the initial implementation, the learning approach and the 3D platform used for each activity, the collection and analysis of data such as the statistical comparison between two different groups or between the pre- and post-activity test. In the light blue area are placed the activities carried out with the GBL approach, reserving the reddish area for the IBL activities.

In the GBL activities, content and learning scenarios were prepared in advance by the researchers. Topics spanned from Agenda 2030 to critical minerals and energy transition. The content was adapted from institutional web sites and research papers. After answering the pre-activity questionnaire, students explored the scenario, performing specific tasks, missions, and quizzes (activities A2a, A2b, A3, A4). Results of those tasks were collected and analyzed but, in addition, students answered to a post-activity questionnaire.

Statistical analysis was performed to compare the knowledge gain of the students (the increase of the percentage of correct answers between the pre- and the post-activity test). In the GBL approach generally students were divided in two main groups. For instance, in the activity A2a, the experimental group or (W group) accessed the virtual world, and a control group (or S group) participated in a sharing screen mode. Test results between the two groups were compared by statistical methods. In some activities (A3 and A4) the two groups accessed two different virtual worlds exploring the same topics and performing the same pre- and post-activity tests.

The activity A2b consisted of a sort of Game of the Goose, where students were the pawn of the game and performed diverse tasks, quizzes and collaborative work.

In the IBL approach students, after a short training, started from an empty scenario, or a basic scenario, to build their own learning path, from the initial idea to the final product. Under the supervision of the researcher, they searched for the information needed to prepare content (e.g.

multimedia presentations, information panels) and built 3D objects (e.g. wind turbines, a metal recycle plant and so on). In IBL activities (A1, A5 and A6) the pre-activity test aims to know the digital skills of students (to address the following training of the use of the platform). Students' knowledge was not tested. In fact, in this type of activity, the final knowledge tests were based upon the content and the artifacts made by students during the experimentation. In activity A5 and A6 students were also divided in two groups, one which accessed the VW and the other which did not, participating or in sharing screen mode or just preparing content with other PC tools.

Regardless of the approach used, in the final test there is always a satisfaction survey regarding their learning experience, the easiness of the 3D platform used and suggestions to improve the learning scenarios. In activity A1, considered as a pilot activity, the control group was not present.

Regarding the time of experimentation, the GBL activities were performed in a 2-hour meeting for each group of students. Sometimes a previous 2-hour training meeting was carried out for the experimental group. On the contrary IBL activities were carried out in several meeting for a total of 20-30 hours.

2.7. ASSESSMENT

For the data analysis an "embedded" mixed method was selected. It is almost a quantitative research design with some qualitative data to highlight students' points of view (Creswell & Clark, 2010). Online forms were used. Teachers' questionnaire is reported in Annex 3.A3a.2. students' questionnaires are reported in Annexes 3.A3a.3, 3.A2a.4, 3.A3.1, 3.A3.3, 3.A5.1, 3.A6.2.

Where a GBL approach is used, a pre-activity test was administered to students for a comparison of results with the post activity test and the calculation of the knowledge gain.

Generally, the pre-activity students' test consists of:

- a section related to general information about students (labeled as G)
- a knowledge test (questions, labeled as T, with single-select multiple-choice questions and multi-select multiple-choice questions, and ordering)
- multi select multiple choice questions on "specific topics" (in some activities).
- a 5-point Likert scale section about their digital skills and knowledge of VW.

For IBL activities the pre-activity test does not include the knowledge tests because in this kind of approach specific topics are developed by students so questions can't be planned in advance. The post-activity test for students consists of:

- a section related to general information about students (labeled as G)
- a knowledge test of the same number of questions of the pre-activity test, labeled as T
- additional questions (in some activities)
- multi-select multiple-choice questions (on specific topics)
- 5-point Likert list of statements about "Students' points of view"
- 5-point Likert list of statements and open-ended questions (satisfaction survey)

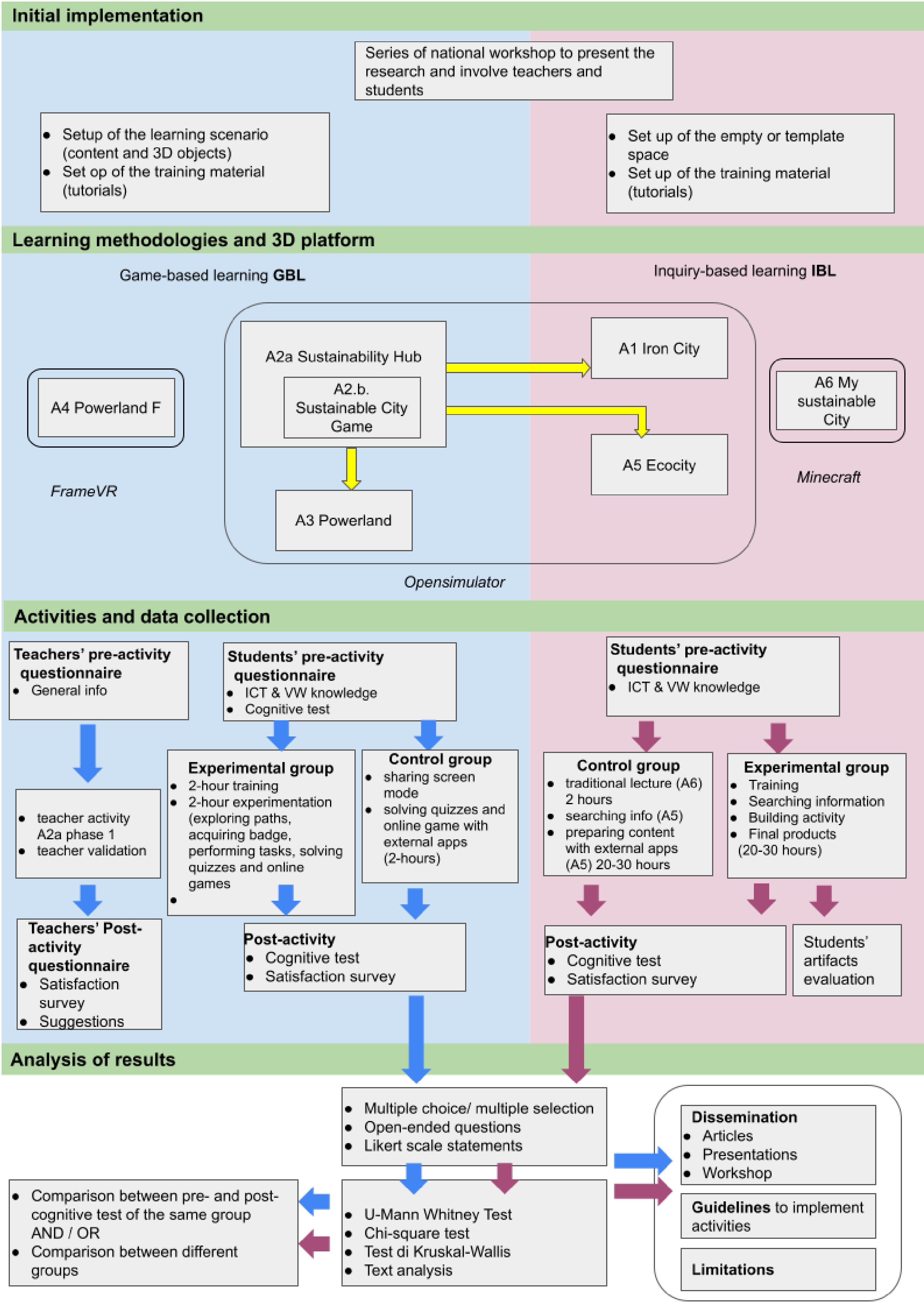

***Figure 2.3.** Flow chart of the activities*

For the teachers, a satisfaction survey /assessment of the activity consists of a series of 5-point Likert list of statements and open-ended questions.

The knowledge assessment tool was validated by a panel of experts of the Geology Division at the University of Camerino and by six teachers involved in the experimentation with students (two of them have a PhD in Geoscience Education and one is a geologist). They judged the knowledge tests adequate for the students.

In each section of Chapter 3 the overall reliability of the students' post activity test (Cronbach alpha) was calculated when needed (Cortina, 1993). Cronbach's alpha is a measure of reliability, or internal consistency, of a set of survey items or test questions. It indicates how well the items are related to each other and measure the same construct. Cronbach's alpha ranges from 0 to 1, where higher values indicate higher reliability.

2.7.1. Knowledge tests

A quantitative approach was used to analyze the results of the knowledge tests of the students. Results were analyzed both in terms of "knowledge gain" (increase in the percentage of correct answers in the knowledge test) between the pre-activity and post activity knowledge tests and comparison between different groups of students (e.g. students which accessed a virtual world and students which do not accessed, or students which accessed two different virtual worlds). The results of the knowledge tests were expressed as mean test score % and related standard deviation.

Statistical tests were performed with the SPSS package (https://www.ibm.com/it-it/spss). In particular:

- the non-parametric test U of Mann-Whitney (Mann, & Whitney, 1947; Moses, 2005) was used to compare the difference between results before and after the activities and between two different groups of students using different protocols of experimentation;
- the Kruskall-Wallis test was used to compare more than 2 groups (e.g. between schools or between students' ages) (Kruskal, & Wallis, 1952);
- descriptive statistics (e.g. frequencies) and Chi-Square tests were used to analyze frequencies of specific questions or multiple choice questions (Humble, 2020).
- when needed the effect size Cohen d was calculated. Cohen (1988) defined the effect size as "the degree to which the phenomenon is present in the population". Effect size is a quantitative measure of the magnitude of the experimental effect. The larger the effect size the stronger the relationship between two variables. It is the difference between the mean of two group divided by the pooled standard deviation. A large effect size is greater than 0.8 (Cohen, 1988).

For each type of test, the statistical significance, in terms of P value (Delampady, 2006), was obtained. All tests were performed at a significance level of 0.05 and a 95.0% confidence interval, therefore, two or more groups were considered statistically significant if P value was less or equal to .05 (Humble, 2020).

2.7.2. Students' point of view and satisfaction surveys of teachers and students

Students' point of view and satisfaction surveys of teachers and students were carried out using Likert scale questions (Likert, 1932). The following Likert scales were used:

- 1 = strongly disagree, 2 = disagree, 3 = neutral / undecided, 4 = agree, 5 = strongly agree (or reversed scale)

- 1 = Extremely, 2 = Very, 3 = Moderately, 4 = Slightly, 5 = Not at all.

Results were analyzed grouping scale 1 and 2, scale 3, scale 4 and 5 and using frequencies, means and/or medians to compare results (Norman, 2010).

2.7.3. Open-ended questions

A content and thematic analysis (Bengtsson, 2016) was used to analyze the open-ended questions of the survey. The phases of the content and thematic analysis are displayed in Figure 2.4. An inductive method was used with a sub system of data to define keywords. Then keywords were used to categorize answers, for instance “sustainability”, “renewable”, “transportation” and so on. Firstly, an electronic sheet was used, followed by a manual checking and refining of the texts recovered. Then a descriptive statistic was applied to calculate frequencies of each selected theme (Figure 2.4).

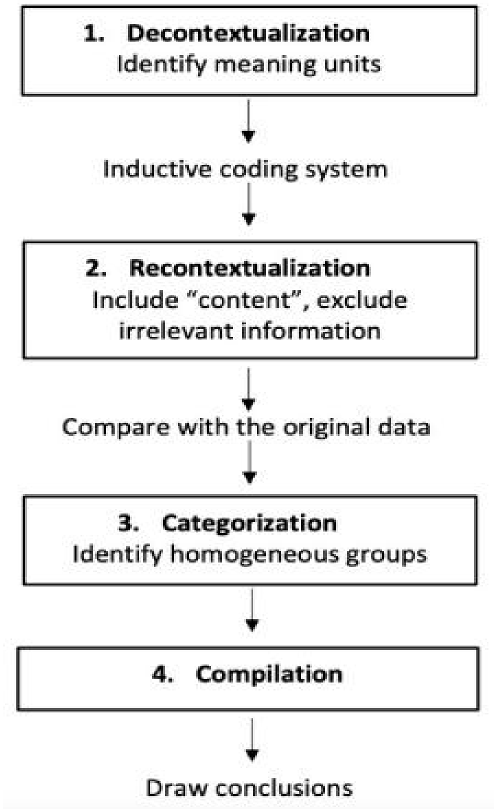

Figure 2.4. *Phases of the content analysis (from Realdon et al., 2020, adapted from Bengtsson, 2016).*

3. Results

The didactic activities created for this research project and the results obtained by testing them are reported in this chapter. It is subdivided in sections, each focused on one of the experimental activities, labelled as A1, A2a, A2b, A3, A4, A5, A6. In Table 3.1. the list of each activity, with the topic addressed, students involved, platform used and students' products is reported.

Table 3.1. *List of the activities experimented in this work (detailed)*

Code	Activity Name	Students' Target	Learning process	Topics	Products	3D platform
A1	Recycle/ Iron City	K7	IBL	Circular Economy & waste management of metals ● Metal Recycle Plant ● Metal properties (Fe, Al) ● Recycle Processes ● Importance of recycle	● Metal Recycle Plant entirely built by students ● Project video made by students ● Storytelling video: Metal Recycle	Opensim
A2a	Sustainability Hub	K6 K7 K8	GBL	General approach to sustainability ● Agenda 2030 SGDs ● Global Challenges ● Georesources and circular economy ● Sustainability Indicators	Educational path to be explored made of: ● Multimedia presentation ● Web linked resources ● Info panel / Videos ● 3D learning objects ● Online games	Opensim
A2b	Sustainable City Game (Section of Sustainability Hub)	K6 K7 K8	GBL	● Agenda 2030 ● Transdisciplinary approach to sustainability ● Sustainable Cities features	A sort of "Game of the Goose" where students/avatar are involved in quizzes, challenges and games individually or in team	Opensim
A3	Powerland-F	K8	GBL	Minerals for Energy and Technology ● Causes of climate change: GHGs ● Energy production: focus on renewable energy ● The CF of energy production ● Critical Minerals for Energy Transition and Technology ● Electric consumption	Educational path to be explored made of: ● Mission Sheet ● Custom electronic sheet for domestic CF calculation ● Custom multimedia presentation ● Link to online games ● Interactive whiteboard	FrameVR
A4	Powerland	K8	GBL	Same as A3	Same as A3	Opensim
A5	Ecocity	K8	IBL-BA	Urban solutions to reduce CF: ● Energy and carbon footprint (CF) ● Urban solutions to lower the CF ● Domestic electricity consumption ● The CF of mobile technology	Students apply solutions to lower CF on a 3D city scenario built by the researcher ● Horizontal wind turbines ● Photovoltaic panels ● Sustainable materials ● Electric power units for cars with solar charging	Opensim
A6	My Sustainable City	K8	IBL	The role of cities in sustainability: ● Buildings ● Transportation ● Energy saving ● Waste management	Students build their ideal Sustainable City. Info source by ● Government reports ● Internet case studies	Minecraft

CF= Carbon Footprint; GBL= Game Based Learning; IBL= Inquiry Based Learning; IBL-BA=Inquiry Based Learning (Blended approach); SDGs' Sustainable Development Goals

At the beginning of each section an infographic displays an overview of each project, using categorized icons to have a first idea about the topic of the activity and details of the methods and experimentation (Figure 3.1).

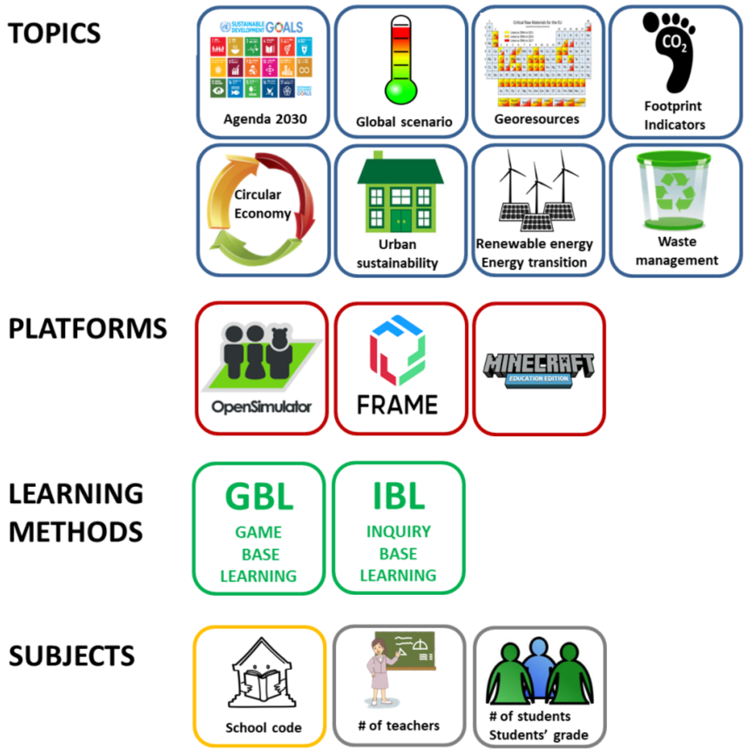

Figure 3.1. *Infographic legend. Source: made by the Author adapting CC0 images or logos. The list of sources is reported in the "List of Figures".*

The results reported in this chapter have been partially published or submitted to journals or published as proceedings in international conferences, as listed in Table 3.2. Presentations to national conferences or to education workshops and fairs are not reported for brevity.

Table 3.2. *List of published or submitted paper related to the activities A1-A6*

Activity	Paper
Techland	Occhioni, M. & Paris, E. (2021). Techland, new educational paths focused on energy, resources and sustainability using virtual worlds. In G. Panconesi & M. Guida (Eds.), *Handbook of Research on Teaching with Virtual Environments and AI* (pp. 316-340). IGI GLOBAL. https:/doi.org/10.4018/978-1-7998-7638-0.ch014
A1	Occhioni, M., Boniello, A., Di Palma, R., & Paris, E. (2020). Teaching Sustainability by virtual worlds as distance learning tool. ICERI2020 Proceedings, pp. 9303-9310.
A2a	Occhioni, M., Beccaceci, A., & Paris E. (2021) "Teaching sustainability and Agenda 2030 topics in virtual worlds". EDULEARN 2021 Proceedings, 5137-5141. IATED. https://doi.org/10.21125/edulearn.2021.1060 Occhioni, M. & Paris, E. (2021). Virtual Worlds to Teach Sustainability Topics in Distance Learning. In C. Busch, R.Frieß, M.Steinicke & T. Wendler (Eds.), *ECEL 2021- Proceedings of the 20th European Conference on e-Learning*, (pp 617-623). https://doi.org/10.34190/EEL.21.133 Occhioni, M., Beccaceci, A. & Paris, E. (2022). Teaching sustainability topics in virtual worlds. A preliminary study. In Electronic Proceedings of the ESERA 2021 Conference. "Fostering scientific citizenship in an uncertain world". J. Bruun & J. Haglund Eds. Part 4 / Strand 4, Digital Resources for Science Teaching and Learning, 315-321. https://esera2021. Occhioni M., Beccaceci A., Paris E. (2023). Environmental education in distance learning: using Virtual Worlds to link geoscience and sustainability. *Journal of Geoscience Education*. https://doi.org/10.1080/10899995.2023.2266863
A2b	Beccaceci, A., Occhioni, M., Stacchiotti, L., Pennesi, D. & Paris, E. (2021). Sustainable City. A serious game in cardboard and 3D virtual versions to engage students in sustainability topics. INTED2021 Proceedings, 4372-4380. IATED. https://doi.org/10.21125/inted.2021.0891 Beccaceci, A., Occhioni, M., & Paris, E. Sustainable City Virtual Game. How to engage students in sustainable lifestyles. Congresso congiunto SIMP, SGI, SOGEI, AIV "The Geoscience paradigm: resources, risk and future perspectives". Potenza, September, 21. Beccaceci, A., Occhioni, M., & Paris, E. Sustainable City Virtual Game. How to engage students in sustainable lifestyles. Rendiconti Online della Società Geologica Italiana (in preparation for submission).
A3 / A4	Occhioni M. & Paris E. (2022). Education and energy transition. A game-based learning approach in an immersive web virtual world. Oral presentation at the 14th International Conference on Educational Technology and Computers, ICECT 2022, Barcelona. Occhioni M. & Paris E. (2023). Critical minerals and energy transition: an educational activity in a webXR virtual world and Opensimulator. Congresso congiunto SIMP, SGI, SOGEI, AIV "The Geoscience paradigm: resources, risk and future perspectives". Potenza, September, 21.
A5	Occhioni M. & Paris E. (2024) "An educational activity on Green Energy in virtual worlds". *Rendiconti Online della Società Geologica Italiana, 62*. https://doi.org/10.3301/ROL.2024.12
A6	Occhioni, M., Di Palma R., Paris, E. (2021). Teaching Urban Sustainability with Minecraft Education edition. 14th annual International Conference of Education, Research and Innovation. https://doi.org/10.21125/iceri.2021.1848

3. A1. Iron City Island / Recycle

Figure 3.A1.1. *Summary of the project*

3.1. AIMS OF THE PROJECT

This project had two main objectives: 1) an educational objective 2) a research design objective. The first aims to increase the students' knowledge about the importance of metals and alloys (in particular Iron, steel and Aluminum), their recycling and the need to increase awareness of the necessity to turn the linear economy into circular economy. The second objective was to test the confidence of students when acting in a virtual world, what kind of training they need, the time necessary to accomplish a thematic project using IBL learning approach. This activity was used as a test for the following activities, to verify contents and methods.

3.2. TOPIC ADDRESSED

In the Agenda 2030 the goal n. 12 "Ensure sustainable consumption and production patterns" and in particular the target 12.2 "By 2030, achieve the sustainable management and efficient use of natural resources" are mainly devoted to natural resources (United Nations, 2015). According to OECD (2019), primary materials (coming from mining) use will double, passing from 89 Gt (in 2017) to 167 Gt (in 2060). The largest share is due to non-metallic materials such as sand, gravel, limestone. Metals share is lower, but increasing faster and with a higher environmental impact. It is estimated that in 2060 production of metals will account for 12% of the total Greenhouse Gases (GHG) emissions. In addition, metal extraction and use have a great impact on environment such as water and air pollution, contribution to climate change, environment disruption for waste landfilling and toxic effects, also on humans. Secondary materials have a per-kg environmental impacts about one order of magnitude lower than primary materials. Increasing of 10% of the recycling rate of steel and aluminum would reduce respectively the average impact on the climate change by 9% and 18%. Abiotic resource depletion would reduce of 38.6% for steel and -23.5%

for Aluminum. Other important effects are the reduction of 52.2% of land use for steel and the reduction of water depletion (25.5%) and the particulate matter production (27.8%) for the aluminum (Dupriez, 2017). So, it is important that students know, also quantitatively, the positive impact of recycling to mitigate climate change, to save energy, to reduce toxic effects.

3.3. DESCRIPTION OF THE LEARNING SCENARIO

As the methodological approach of this activity is IBL, the learning scenario was completely built by students under the supervision of the class teacher and the researcher. It consists of a metal recycle plant, including the sorting section and a simplified version of steel mills and aluminum re-melting treatment line. Some objects were imported from 3D model sites or other Opensimulator-based virtual worlds.

3.4. STUDY POPULATION

This pilot study involved 8 students (6 males, 2 females) all K7 grade (13 years old) of the school N and their science teacher, Raffaela Di Palma, who acted as the external observer and contact persons for communication between students and teachers. Two other teachers were external observers during the test, without interaction with students, with the role to observe the student's activity and report any problem.

3.5. PHASES OF THE PROJECT

During the lockdown due to COVID-19, in one of the islands of Techland, Iron City, a 3D collaborative learning environment has been set and tested. It was a pilot project in the frame of a joint program with schools to implement educational paths about environmental sustainability, circular economy and the Agenda 2030 Sustainable Development Goals. It focused specifically on the importance of metals in society and the advantages of their recycling, to save resources and energy. It is important to address these issues to make aware the new generations towards a more efficient use of resources: this activity is also part of the teaching of Environmental Education and Technology courses at school.

The project has been carried out in May/June 2020, starting during the COVID-19 lockdown but continuing following the students' request after the school ending. All participants involved accessed Techland from home only. The project was scheduled in 2 hours modules twice a week, with a total of 20 hours, leaving students free to access Techland even outside the scheduled meetings, individually or in groups.

We used virtual worlds in conjunction with a collaborative platform, the official platform used to schedule all the school activities, for official communications and for repository of material at the end of experimentation.

The activity, of which some moments are shown in Figure 3.A1.2, was divided in the following steps (Figure 3.A1.3), with indication of the time dedicated to each of them:

- Initial activity (1 hour): in the first meeting digital questionnaire were delivered to the students to detect their initial technical competence: considering the type of approach (IBL) and the digital products to develop, it was useful to know their initial digital competence to plan the training required. Info about the apps commonly used by the students to record PC screen, to edit video and audio and for 3D modeling were also collected. Then, teachers explained the objectives of the project and assigned the task to be accomplished: the reconstruction of a metal recycle plant, as an example of one of the pillars on which circular economy is based.

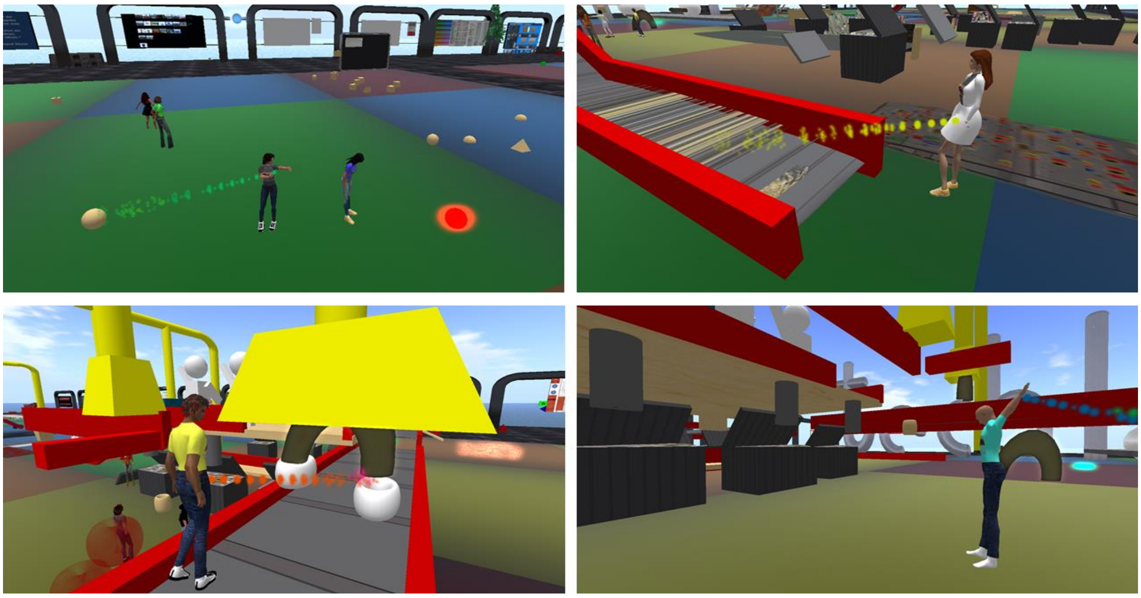

Figure 3.A1.2. *Students at work.*

- Training: 3 hours were devoted by student to master the main functions of the viewer Firestorm used to access the world (how to move in the world, how to import images how use the text and voice chat, how to make short programs to give "behavior" to the objects) and familiarize with the building tools. This was accomplished by tutorials placed inworld and by screen share.
- Get information (web research - 2 hours plus homework): students initially consulted a given list of websites made available directly from the world, clicking on a system of panels, but they were free to also explore other resources about metal recycle plants, steel mills, use of metals, circular economy. This activity was continued by the student individually at home until the following meeting.
- Briefing activity: this activity took place at the beginning of every meeting, initially to define the role of each student in the project, to share ideas and jobs, to outlining the layout of the recycling plant and deepen the process phases annotating the main information. Then, in the following meetings, it was useful to verify the state of the art.
- Building: In 10 hours total, students accomplished the reconstruction of the plant following the outlined scheme. It was a collaborative work where students shared information and suggestion in the voice chat. The building tools allow them to place on the island different "primitive" shapes, called "prims", that can be resized, rotated, warped, texturized and programmed. Objects were made interactive by clicking on them, to provide information and to simulate movement (for example the conveyor belt of the plant, or still rolling mills). In this phase teachers acted as supervisors, leaving pupils free to express their potential and giving suggestion just in case of need. In fig 3 the phases of the metal recycling process are displayed. The overview of the finished plant is shown in figure 3.A1.1.

- Develop contents (1 hour plus homework): along the various parts of the plant, students placed information (pictures, clickable notecard, panels, multimedia presentations). Their function was intended to fix some important notions to learn or remember and to support other cohorts of students visiting the plant in the next years.
- Make a screencast video (2 hours): at the end of the project, a screencast video was made to explain how a metal recycle plant works. Screencast videos are also called “machinima” the merge of the words machine and cinema (Marino, 2004). To produce this video students first wrote the storyboard and then recorded the audio of the characters, Then the actors/avatars were “forced” to play gestures, lips movements, facial expression by means of special animations controlled by the user/student, while they explained all the recycle phases. Videoclips recorded are then joint in post-production, also adding voice and music. Screen casting captured the in-world activity in real time using the engine of Opensimulator as a virtual film studio with tools as lighting, staging, and camera view (Lowood, 2006).
- Final activity: (1 hour). Final tests and surveys.

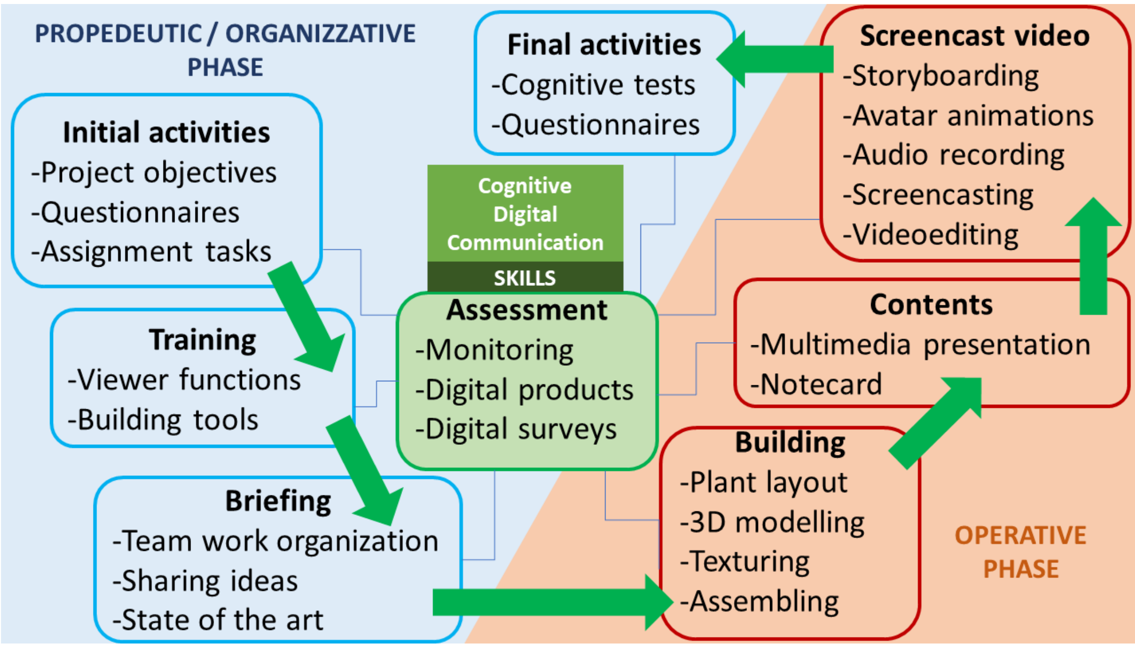

Figure 3.A1.3. *Phases of the project*

3.6. RESULTS

In virtual worlds students can perform authentic activities or tasks as they were in real world (Reiners, 2011) and teachers can analyze their learning in different ways, especially in collaborative projects. In this experimentation, the students were evaluated in multiple ways, as described in the following.

3.6.1. Monitoring

Students were observed while acting in the world and building the plant, and during the briefing activities in videoconference. Teachers observed students while working individually and during teamwork, annotating how they planned and divided jobs, following their natural attitudes, without assignments by the teachers. In addition, they observed the students' reactions and their comment during the working time and the briefing.

By moving in the virtual space with their avatar, the students experienced the possibility of being able to move, run, "fly", "teleport from one region to another" while in "real life" they were forced to remain closed in their own family environment. Therefore, the ability to explore space, to get close with your avatar to a classmate's one and to the teacher has certainly triggered positive emotions, as was observed in videoconference, filling the gap of the physical distance, the isolation, imposed by the lockdown and contributing to the possibility of entering a relationship with the others. This confirms that virtual worlds represent an enriching resource and an innovative potential in the teaching-learning process at a distance. The pupils were always present, active, and participatory in the experimentation, despite the morning commitments of distance learning and the participation in different extracurricular projects in the early afternoon of the same day. In addition, although school had finished ten days before, they wanted to finish the plant and the video, continuing the meetings and the work.

3.6.2. Final products

The final products of the project have been the metal recycle plant itself (Figure 3.A1.4), the information enclosed (multimedia presentation and notecard), and the screencast video. Table 3.A1.1 summarize the digital products, the contents and the elements used to evaluate each of them, from which it is evident that different skills and contents are required to create a digital product. Video can be seen at the following link:

https://www.virtualscience.it/video/riciclo_metalli.mp4.

Table 3.A1.1. *Evaluation of digital products.*

		Element of evaluation		
Digital product	**Contents**	**Knowledge**	**Digital skills**	**Communication skills**
Metal Recycle Plant	-Recycling process. -Steel mills	-Correctness of the recycle sequence process	-3D modelling -Image editing -Coding	-"Walkability" -Easy recognition of different zones
Information	-Properties of metals -Use of metals -Elements of circular economy -Recycling	-Correctness of the information -Topics in-depth -References	-Graphical features of the multimedia presentations and notecards	-Texts -Readability
Screencast video	-Importance of metals -Summary of the process	Correctness of information	-Screen casting -Video editing -Audio recording	-Storyboard -Avatar animation

3.6.3. Knowledge test

At the beginning of the new school year, three months after the experimentation, a knowledge test was delivered to the pilot group to verify the persistence of the knowledge acquired about sustainability and metal recycling thanks to the project. A set of questions, either multiple choice or open answers, was delivered by an online form. The questionnaire aims to assess three main topics: Metal properties, metal recycle process, the importance of recycle. In table A1.3.2 results are reported. In annexes 3.A1.1, 3.A1.2, 3.A3.3 the pre-activity and post-activity tests and the detailed answers are reported.

Table 3.A1.2. *Persistence of the knowledge acquired (3 months after the experimentation).*

TOPICS / RESULTS	Metal properties	Metal recycle process	The importance of recycle. (open-ended answers)
Right answers	100%	75%	
Highlights			
-Saving resources			88%
-Saving energy			88%
-Less pollution			75%

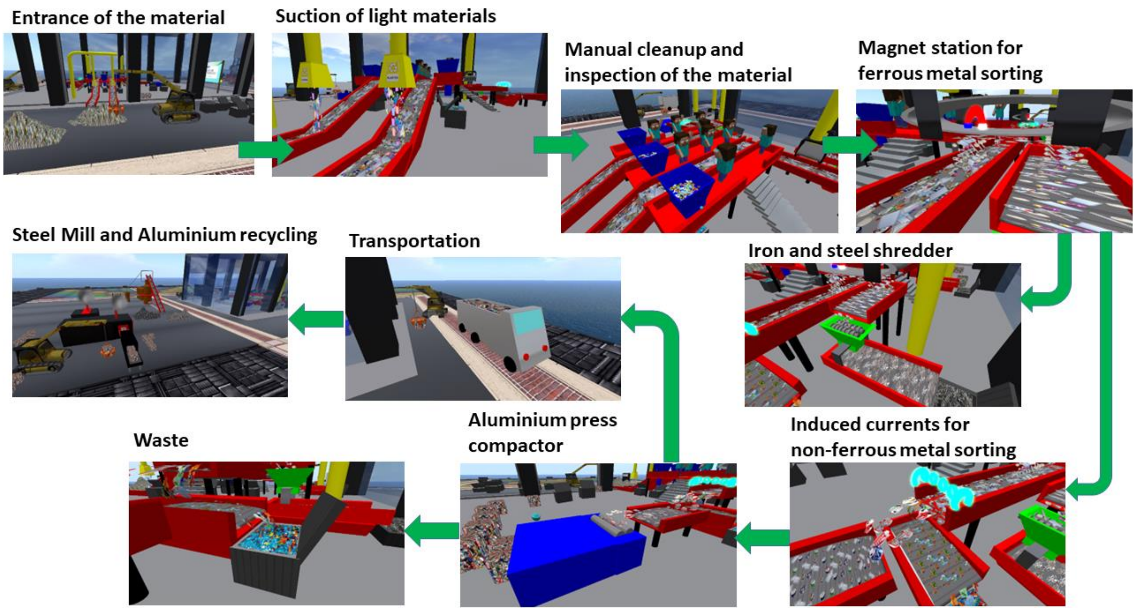

Figure 3.A1.4. *The metal recycle process.*

3.6.4. Satisfaction survey and digital skills

From the analysis of the initial questionnaire (Annex 3.A1.3), it resulted that students did not know Opensimulator-based virtual worlds but were very familiar with Minecraft (https://www.minecraft.net). They knew applications to write text, to make multimedia presentation, to screencast and edit videos. Some of them were familiar with desktop 3D modeling applications (Figure 3.A1.3.5). Online forms were used to collect students' opinion to evaluate the perceived level of their digital skills, using a Likert scale (Table 4). By means of questionnaires delivered to the students at the end of the project emerged that: 1) They found no particular difficulty in act and interact in the world. Sometimes, some of them experienced lag problems due to connection or PC requirements. 2) All of them improved their technical skills; when this did not happen, it was because the student was already familiar with some of those skills also before the project.

Here is reported an open-ended answer of a students, as a general rating of the experience: "*I really enjoyed participating in this experience because of the fact that you could communicate and build together with your classmates when you wanted to and not necessarily only during class. it was a very good experience it helped me to have a good time during the months of lockdown".*

Other considerations on learning experience are reported in Section 3.S.

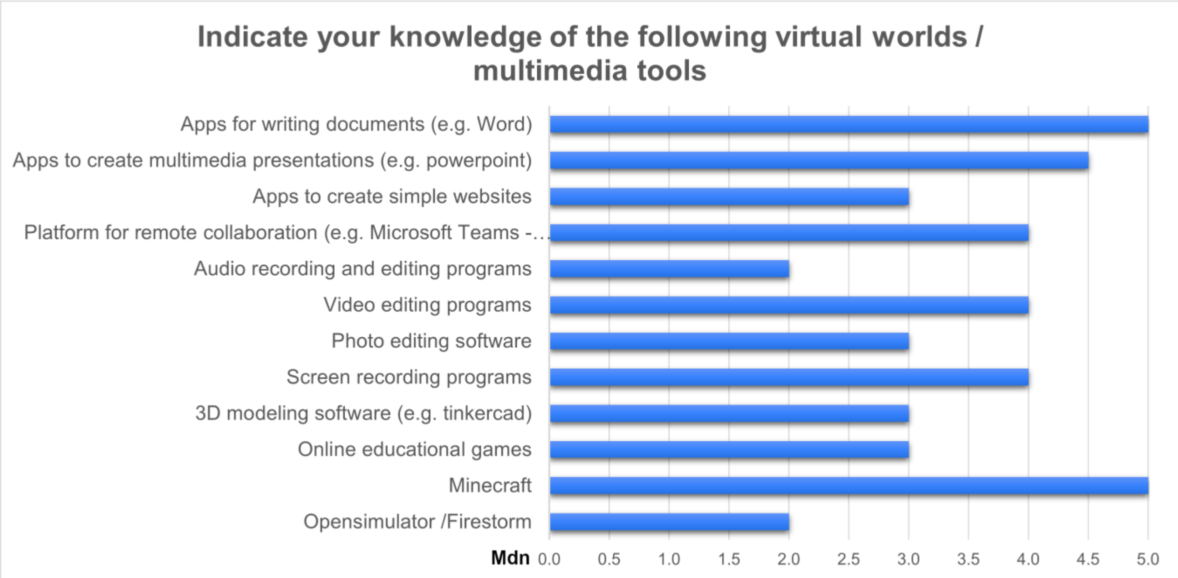

Fig. 3.A1.5. *Level of students' mastering of virtual worlds / multimedia tools.*
(Likert scale: 1 = None; 2 = Poor; 3 = Basic; 4 = Good; 5 = Excellent

3.7. DISCUSSION

The IBL methodology applied to virtual worlds, in conjunction with the production of the screencast video, allowed students to improve different digital skills in the same environment (video e photo editing, screen capture, coding, 3D modelling, web research). Screencast videos are an original way to report about projects, tell stories (digital storytelling) or express personal point of view and creativity. In addition, the occasion of learning in virtual worlds, where the interactions are generally synchronous can be extended in an asynchronous way through screencast videos (machinima videos), using them as a resource material for other students (Kirriemuir, 2007).

An important role was played by the "sense of presence" and the social interaction (Dede, 2009) in an emergency context where this interaction was inhibited: the lack of laboratory activities, due to pandemic, was overcome by the use of virtual words, that gave students the perception to be active and productive, making activities as they were in real life, although they couldn't leave home, and helped them feeling really in touch with their classmates, introducing moments of interaction and socialization.

Students' participation and engagement in conjunction with knowledge test results demonstrate how students, adequately motivated, learn with pleasure, participate with enthusiasm, learn by playing, acquiring also new skills. In addition, other than learning about metals, metals production, recycling and circular economy, working in a virtual world let them to improve multiple aspects of their digital skills.

These results encouraged us to experiment virtual worlds at large scale to implement sustainability topics. Considering the ease of use perceived by the students, we decided to have just one training meeting for the following experimentations.

3.8. CONCLUSIONS

The COVID-19 pandemic and lockdown periods evidenced how it is important for teachers to have access to a variety of teaching methods and activities, especially to overcome the social distancing imposed by pandemic that caused the unavailability of real labs. Virtual worlds can be useful to engage all kinds of students in science topics, even the less motivated, and to allow personal or professional development also improving the students-students and students-teachers relationships.

Virtual worlds, being flexible and easily adaptable to different subjects and context, evidenced to be remarkable and effective tools for Distance Learning in the lockdown period, but also in normal school time, where could be used as a valid and motivating support activity to traditional teaching.

3. A2a. Sustainability Hub Island

Figure. 3.A2a.1. *Summary of the project*

3.1. AIMS OF THE PROJECT

The educational activity presented here (called Sustainability Hub) was planned to help students to approach the basic concepts of environmental sustainability by a didactic activity using virtual worlds in distance learning (Figure. 3.A2a.1). After this activity, the students can deepen specific topics in other islands of the Sustainability section. The activity was divided into three phases:

Phase 1: experimentation with teachers

Phase 2: experimentation with a group of 92 students

Phase 3: experimentation with a larger group (583 students)

The planning of the island and the activities of PHASE 1 and 2 were carried out in collaboration with the PhD colleague Alessandra Beccaceci (UNICAM).

3.2. TOPICS ADDRESSED

On September 25th, 2015, the UN General Assembly adopted the Agenda 2030 for Sustainable Development, a global framework to address sustainable development. The 17 Sustainable Development Goals (SDGs) cover global challenges for Humanity, and they are divided into 169 total targets (UN, 2015). Goals and targets are addressed in a holistic view, joining together the environmental, social and economic dimensions.

Gill (2016) stressed the importance and the role of Geoscience in addressing sustainable development SDGs. Among them, food security (SDGs 2 and 3) by preserving agricultural soil; access to clean water (SDG 6); energy transition (SDG 7) highlighting the potentials of renewable energy; the sustainable exploitation of resources (SDG 12); and climate change (SDG 13) and the mitigation of its effects. Therefore, the main topic addressed at Sustainability Hub are geoscience-related:

- General approach to sustainability
- Climate change and environmental parameters
- Georesources and circular economy
- Environmental footprint indicators
- The Agenda 2030 and its state of the art

All topics were elaborated using data from government websites, official documents, and geoscience research articles (Table 3.A2a.1).

3.3. DESCRIPTION OF THE LEARNING SCENARIO

In the same scholastic year of the Italian Environmental and Civic Curriculum's adoption, the COVID-19 pandemic forced most of the Italian schools to adopt a distance-learning mode. Some classes were totally in remote learning, some classes in-person, and others in a blended mode, depending on different regional restrictions. Therefore, the long period of COVID-19 pandemic made remote activities highly relevant for education and for the completion of the scholastic year. Then, it was evident how there was a strong need to make available to teachers' activities to approach the new themes of Environmental Education, including practical activities and the use of digital tools. In this framework, immersive VW could have been useful for teaching, as well as to motivate pupils, giving them the chance to socially interact with other students in the lockdown periods, while carrying out school activities.

For these reasons, during the long COVID-19 lockdown periods it was decided to build and test a VW devoted to sustainability, making it available to four Italian schools, for a large experimentation of the new school curriculum. The project was aimed to approach the themes of sustainability, especially those most linked to georesources, also giving the possibility to carry out practical activities despite schools' closure due to the pandemic. The affordance and features of VW and the main pedagogical approach used are described in Chapter 1.

The Sustainability Hub island (Figure 3.A2a.1) is the "landing point" of the Sustainability section of Techland. The island is connected by a teleporting system" to other islands where some topics are deeply treated, and specific paths are presented. Sustainability Hub island is divided into six different areas, each related to a different topic. These areas are: Welcome area, Global issues scenario, Georesources, Environmental footprint indicators, Agenda 2030 and Sustainable Development Goals, Sustainable City Game (Figure 3.A2a.2).

Welcome Area introduces visitors to the map of the island and the various themes or activities which are possible to carry out. Here they also get acquainted with the major functions of avatars and objects to be found during the visit. In the Welcome a delimitated space act as "sandbox" where students can experiment some building activities.

Global issues scenario area is a general introduction and presents the major issues humans must face to target the SDGs: climate change, loss of biodiversity, world population growth, hunger and poverty and overexploitation of resources figured out by the Earth Overshoot Day.

Georesources area reports information and data regarding the use and consumption of water, soil consumption, energy, critical minerals. The role of waste in the circular economy is highlighted (https://ellenmacarthurfoundation.org/) such as the Waste from Electrical and Electronic Equipment (WEEE), the recycling of glass, metals and plastics and the organic waste to produce of bioplastic or compost.

Table 3.A2a.1. *Topics addressed in Sustainability Hub reporting main (but not exhaustive) source of information used in this activity*

Topic	Definition	Source of information
Agenda 2030	This Agenda is a plan of action for people, planet and prosperity. It also seeks to strengthen universal peace in larger freedom	https://www.un.org/ https://www.unesco.org/en Italian Alliance for the Sustainable Development - https://asvis.it
Overshot day (EOD)	EOD) "marks the date when humanity has used all the biological resources that Earth regenerates during the entire year".	www.overshootday.org
Climate change and its effects Greenhouse emissions		https://www.unesco.org/en the Intergovernmental Panel on Climate Change reports, IPCC https://www.ipcc.ch/ NASA - https://climate.nasa.gov/ https://www.nationalgeographic.com
Georesources		https://www.usgs.gov/ https://www.fao.org/aquastat/en/
(WEEE)	Waste from Electrical and Electronic Equipment	https://environment.ec.europa.eu/topics/waste-and-recycling/waste-electrical-and-electronic-equipment-weee_en
Carbon Footprint	A measure of the total amount of CO_2 and CH_4 emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest.	Matuštík, J. & Kočí, V. (2021 https://www.carbonfootprint.com/calculator.aspx
Material flow indicator (ecological rucksack)	An Ecological Rucksack is the total quantity (in kg) of materials moved from nature to create a product or service, minus the actual weight of the product. That is, ecological rucksacks look at hidden material flows. Ecological rucksacks take a life cycle approach and signify the environmental strain or resource efficiency of the product or service.	https://www.gdrc.org/sustdev/concepts/27-rucksacks.html https://ec.europa.eu/eurostat/documents/1798247/6191533/3-Economy-wide-material-flow-accounts...-A-methodological-guide-2001-edition.pdf/
Ecological footprint	The aggregate area of land and water in various ecological categories that is claimed by participants in that economy to produce all resources they consume, and to absorb all their wastes they generate on a continuous basis, using prevailing technology	Matuštík, J. & Kočí, V. (2021
Hidden water Water Footprint	Hidden water is "water that is not felt or seen and it is required for almost every step in the production processes for many raw materials and finished products"	www.watercalculator.org
Circular Economy	The circular economy is a systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution.	https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

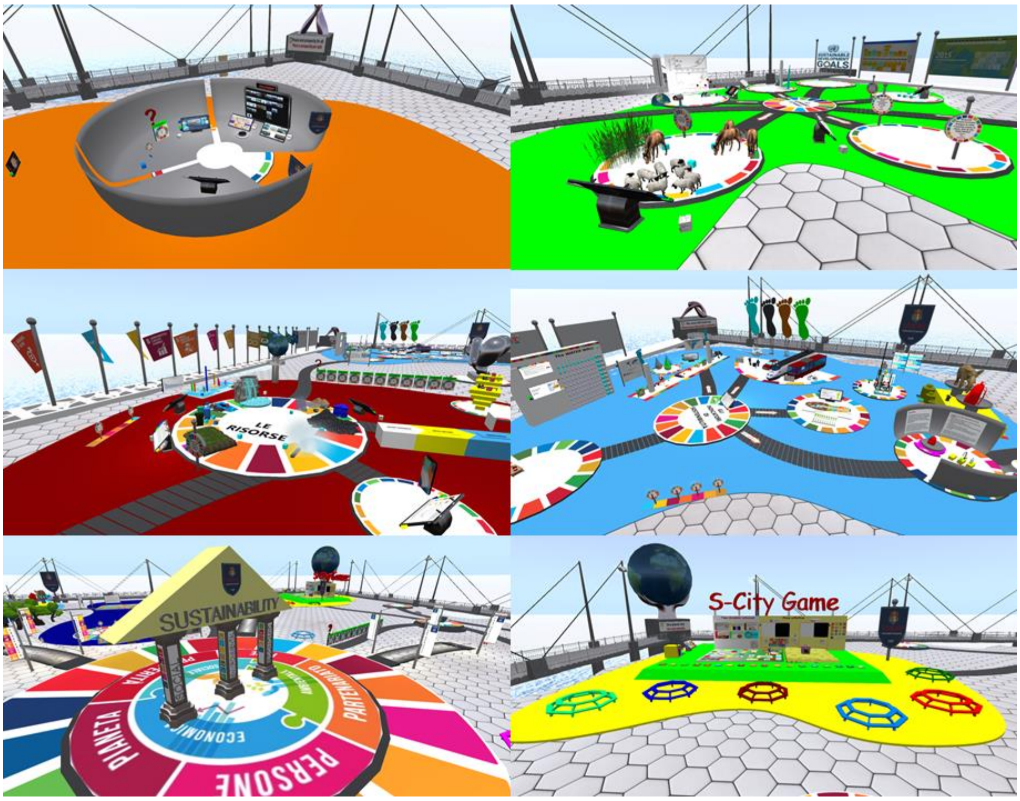

Figure 3.A2a.2. *Thematic sections of the Sustainability Hub. Top to bottom and left to right: the “Welcome Area”, the “Global Issues Scenario area, the “Georesources area”, the “Environmental Footprint Indicators area”, the “Agenda 2030 and Sustainable Development Goals area”, the “Sustainable City Game area”.*

Environmental footprint indicators area focuses on various tools to assess the pressure of human activity on Earth, such as carbon-, water-, and ecological footprint (Matuštík & Kočí, 2021) and the Material Flow Indicator called also Ecological Rucksack (European Commission, 2001). Interactive 3D objects, graphics and reference tables help students calculate the impact of their daily routine actions, compare the carbon footprint of different types of transportation or evaluate the water “hidden” in the production of daily-used materials (water footprint).

Agenda 2030 and Sustainable Development Goals area gives an introduction to the Agenda 2030 and the timeline of events that led to its birth, the concept and definition of sustainability and the importance of its environmental, social and economic pillars. In the SDGs path, students can explore all the Sustainable Development Goals and their targets. In this section students can also find the “state-of-the-art” of the Agenda 2030 in Italy.

Sustainable City Game area represents the final part of the experience, where students optionally play a virtual version of a sort of the Goose game (a board game where two or more players move pieces around a track by rolling dice) (Beccaceci et al., 2021). In this virtual version, students/avatar, alone or in a team, are the pieces of the game and, to win the game, must solve quizzes and challenges on topics related to the themes treated in the Hub. The Game is explained in detail in section 3.A2b.

Students find engaging activities along the path, aimed to focus on the themes of sustainability in different ways. In each area teacher and students deal with:

- info panels reporting driving questions for students and the list of the main topics
- multimedia presentations

- links to external resources
- link to online games developed with specific apps such as learning up (learningapps.org) and genially (genial.ly)
- Practical interactive activities such as the ecological and carbon footprint calculator to assess the impact of domestic daily activities, the “waterwall” to calculate the water footprint of food.
- Interactive 3D objects, which are “animated” objects. When clicked they can change size, color, position, transparency to display concepts, data and information. Examples of 3D learning objects are shown in Figure 3.A2a.3.
- Interactive graphs, to collect data
- interactive quizzes, to be solved at the end of each section. A typical 3D quiz is a 3D panel showing in sequence, when clicked by the avatar, a fixed number of multiple-choice answers, related to the content explored by students in the relative section. For each 3D quiz, a badge was automatically provided to the students in case of full score, to testify the completion of the relative topics and encourage students to complete their tasks in a gamification approach (Deterding et al., 2011)

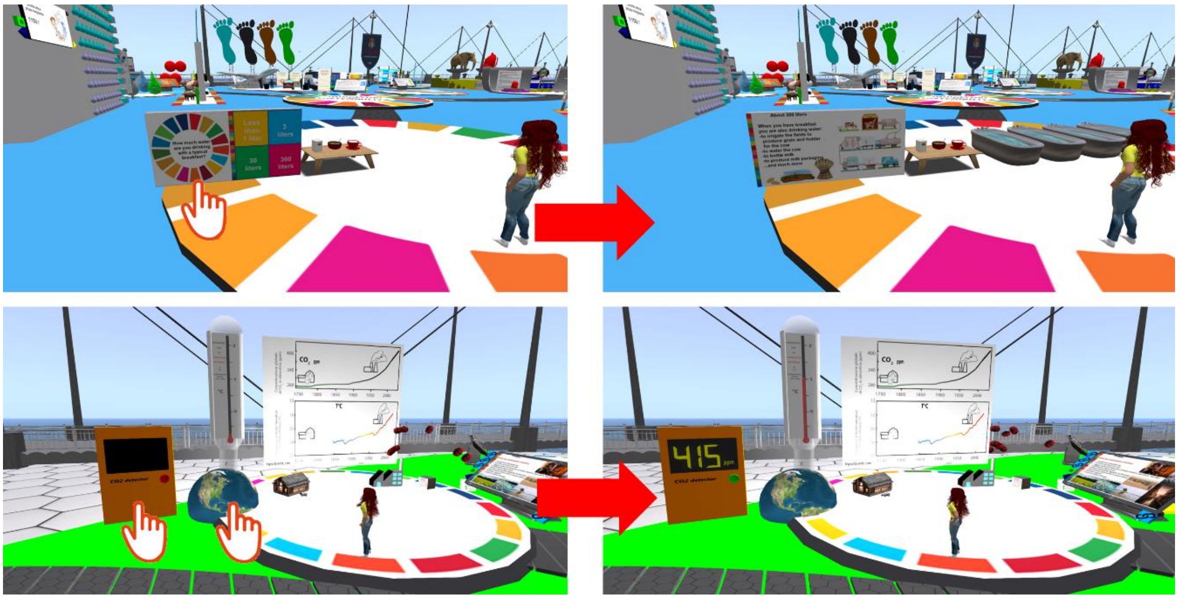

Figure 3.A2a.3. *Examples of 3D learning objects in the Sustainability Hub, activated by avatar’s click. On the top, as an example, the water footprint of a typical breakfast, corresponding to about 4 bathtubs full of water. On the bottom, the actual level of CO_2 in the air and the difference of the mean temperature respect to the pre-industrial level.*

3.3.1. Pedagogical approach

In the Sustainability Hub, the educational paths have been structured to be experienced in different ways, according to teachers' time, availability and interests, as follows:

- using a structured path explored by students, consulting material and solving quizzes and games (gamification approach or GBL). Students can act interactively, alone or in a group, with or without the supervision of the teacher. Pellas and Mystakidis (2020) highlighted the high number of papers present in the literature, attesting that students who participate in VW with a GBL approach get better outcomes with respect to traditional lectures also thanks to the access of many sources
- the teacher lets students build up their own path, developing a collaborative project following a theme or assigning a specific task or a practical activity (Inquiry based learning approach, IBL)

(Dow et al., 2014). These types of educational paths are highly effective and involving, but need several meetings to be accomplished

In the present work, the GBL approach was chosen. The IBL was reserved for specific topics to be deepened with specific internal and web-linked resources. Practical activity in Sustainability Hub or in other connected islands was also involved, actively engaging students in building activity and collaborating to set up 3D objects and information to show their findings and their points of view (Occhioni, 2020).

3.4. STUDY POPULATION

3.4.1. Teachers

Fifty-eight teachers, from all over Italy, were recruited on a voluntary basis among those who participated in the University of Camerino webinars about Sustainability. Among them, 82.8% were female and 17.2% were male. The age of participants varied from 30 to 65 years. Most of them (77.6%) taught in lower secondary schools (students' ages 11-14 years old), and they were mostly STEM (Science, Technology, Engineering, Mathematics) teachers (79.3%). The teachers tested the didactic activities of the Sustainability Hub before the students, providing useful suggestions; 11 teachers acted as observers during the activity carried out with their students.

3.4.2. Students

A large number of students (650, 51.7% female, 48.3% male) were involved. They were all from four lower secondary schools, each from a different area of Italy (North, Central and South Italy). In this study, the schools were labeled with the letter C, D, F, and N. In terms of age, students were divided into categories: 11-12 years old, 13 years old and 14 years old (K6-K7-K8). For privacy, data related to students' ethnicity and socioeconomic condition were not collected. In Tables 3.A2a.2 and 3.A2a.3 and in Figure 3.A2a.4 the distribution of students by schools, grade and gender is reported. About 89% of the total students involved in the experimentation filled the post-activity questionnaire.

Table 3.A2a.2. *Number of students by school, grade, and gender. Pre activity*

Grade	Gender	School				Total	
		C	D	F	N		
K6	Male	9	0	55	0	64	133
	Female	9	0	60	0	69	
K7	Male	21	52	47	14	134	279
	Female	19	55	56	15	145	
K8	Male	10	0	91	15	116	238
	Female	9	0	105	8	122	
	Total	77	107	414	52	650	650

Table 3.A2a.3. *Number of students by school, grade, and gender. Post activity*

Grade	Gender	School				Total	
		C	D	F	N		
K6	Male	9	0	51	0	60	117
	Female	7	0	50	0	57	
K7	Male	19	45	42	14	120	242
	Female	16	48	43	15	122	
K8	Male	9	0	88	15	112	216
	Female	5	0	91	8	104	
Total		65	93	365	52	575	575

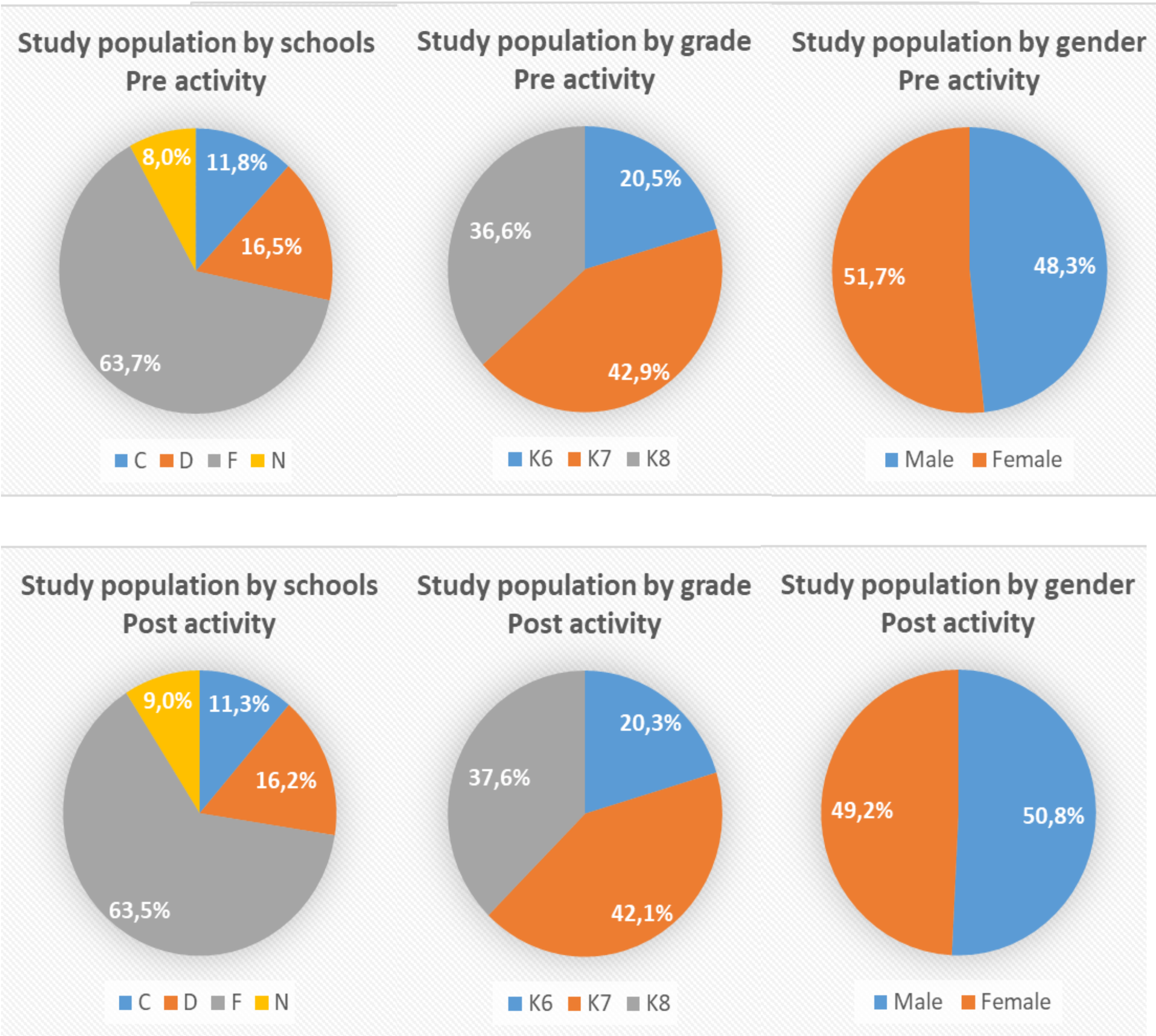

Figure 3.A2a.4. *Study population by schools, grade, and gender. Top: pre activity; Bottom: Post activity*

3.5. PHASES OF THE PROJECT

The activities were divided into three phases (Figure 3.A2a.5).

Phase	Schools	Pre-activities	Activities	Evaluation
PHASE 1	From many Italian schools		Teachers (58) • 2 meetings (2h each) • training • free exploration of the island	• General info on Civic Education curriculum • Satisfaction survey • Project evaluation
PHASE 2 PHASE 3	4 K6-K8 schools C D F N	PRE ACTIVITY TEST • General Info • Cognitive test • Digital skills info	S Group (439 students) 1 meeting (2h): • interactive screen-sharing lesson W Group (136 students) 2 meetings (2h each) • training • free exploration of the island	POST ACTIVITY TEST • Satisfaction survey • Cognitive test
		Group choice S or W based on: • home PC availability • PC requirements • Extra-curricular time • Teachers' time availability and interests	Monitoring Teachers (11) • Observation • Monitoring students' activities	• Project evaluation • Students' behaviour evaluation

Figure 3.A2a.5. *Phases of the project*

PHASE 1: Before starting the activities with students, 58 teachers were involved, divided in two groups, first a group of 21, then a second group of 37, given the high interest shown by other teachers to participate. The preliminary activity with teachers aimed to illustrate the project, letting them explore the island in the same conditions as the students. The teachers involved in phase 1, after one 2-hours training meeting, were free to explore the island, consulting resources and carrying out activities, by means of their personal avatar. (Figure 3.A2a.6).

Figure 3.A2a.6. *Teachers during a session*

PHASE 2. Activities with a pilot group was carried out with 92 K7 and K8 grade students of 2 different schools (labeled as N, C), 87 of whom also answered the post-activity questionnaire (Occhioni et al., 2021). This phase aimed at a first evaluation of the educational path and to refine the educational protocol, test the content and the technical procedure. The students were divided into groups W and S. Three teachers were involved as observers.

PHASE 3. Activities at the large scale were carried out with 558 students (K6, K7 and K8 grade,11-14 years old). Regarding the students, 488 of them also answered the post-activity questionnaire. The activities followed the same protocol of phase 2. Three schools were involved in this phase, labeled F, C, D. Students of the school C were different with respect to phase 2. Eight teachers were involved as observers.

The total number of students who responded to the post-activity survey of phase 2 and phase 3 was 575, with 76.3% in group S and 27.7% in group W. Students came from 31 classes, of which 19 were totally in sharing screen mode (S-type classes), 3 were totally in the virtual world (W-type classes) and 9 had some of the students in sharing screen mode and some other students in the virtual world (WS-type classes). In each session approximately 16-28 students took part in the activities.

As the research was carried out in the first five months of 2021, during school restriction due to the Covid-19 pandemic, schools were closed and all students and teachers participated in the activities from home. Students at home often had PCs that did not meet the requirements or had to be shared with other siblings in distance learning, often without a good internet connection. In addition, mobile devices do not have the technical requirements to allow students to access the world. Therefore, to overcome these inconveniences, students were divided into two groups, called WORLD group (W, students who have accessed the "Sustainability Hub" island through their own avatar) and SCREEN group (S, students who participated in the activities in sharing screen mode). Three classes out of the 31 involved were totally in the W group. In Table 3.A2a.4 is depicted the different approach of the two groups.

Table 3.A2a.4. *Activities of the group S and W*

Action	Screen-Sharing Group (S)	Virtual World Group (W)
Participation	Screen sharing mode by collaborative platforms (2-hours activity)	Access to Sustainability Hub as avatar (2-hours of training and 2-hours of activity in 2 different meetings).
Exploration	Guided exploration of the researcher avatar in screen sharing mode	Free exploration of the island Sustainability Hub
Interaction	Observing the interaction through the researcher avatar	Interaction with 3D objects to visualize concepts and get information
Communication	Meeting chat	Text chat and voice
Information fruition	Multimedia presentation by researcher in sharing screen mode	Use of educational resources independently (multimedia presentation, external web links and games)
Interactive games	Online Games (learningapp.org; genially.org)	Online Games (learningapp.org; genially.org)
Discussion	Brainstorming with teachers and researcher	Brainstorming among pairs
Self - assessment	Online forms	Interactive quizzes on interactive panels
Deepening	Consulting delivered multimedia presentation	Access to the island also at own student's pace

Students of the W group were previously provided with an avatar and instructions to log in to the island and two 2-hour meetings were organized. In the first, they became familiar with the various functions of the viewer and learned how to customize the avatar, how to move and orient themselves in the different zones, and how to communicate with other avatars and interact with objects. To avoid the risk that pupils consider the VW just a game, it was important to dedicate a little time at the beginning to make the students familiar with all the tools, but also explain the educational goals and the tests they had to take in order to proceed and complete the tasks successfully.

In the second meeting they were free to explore, following or not a specific route, all the areas of the island but the "Sustainable City Game", to be played in a third 2-hour optional meeting. Students consulted content (presentations, videos, documents, websites…), made practical activities (such as calculate the carbon footprint of daily routines or "paint" the Waterwall, a 3D wall to be covered of metaphoric drops of water, which represent the water footprint of students' favorite food), and answered the interactive quizzes at the end of each zone. A typical 3D quiz is a 3D panel showing, when clicked by the avatar, multiple-choice questions, related to the content explored by students in the related zone (Figure 3.A2a.7). For each 3D quiz, a badge was automatically provided to the students in case of full score, to testify the completion of the relative topics and encourage students to complete their tasks in a gamification approach (Deterding et al., 2011). Questions in the 3D interactive quizzes are reported in Annex 3.A2a.1.

Figure 3.A2a.7. *Students challenging with badge quizzes.*

In the SCREEN group (or S) the pupils participated in the activities through screen sharing, using a conference platform, in only one 2-hour meeting. In this case the researchers' avatar acted as a kind of mediator interacting in their place and showing the content of the island. The interactive quizzes and online games were carried out by the students by providing them the related links in the meeting chat. The screen sharing mode was chosen for the entire class by the teachers, based on an evaluation of the availability of devices and the quality of internet connection of the students at home, or to avoid inequalities among students. In some cases, the teachers left the students free to choose the mode they preferred.

3.6. RESULTS

3.6.1. Validity and reliability

The knowledge assessment tool was assessed for validity by a panel of experts of the Geology Division at the University of Camerino and by six teachers involved in the experimentation with students (two of them were PhD in Geoscience Education and one was geologist). They judged the knowledge test adequate for the students. The overall reliability was alpha =.60 for the knowledge test based on school N, the first school which carried out the activity. When Cronbach alpha values are below 0.7 usually there is a need to be cautious in interpreting results. The value of reliability <0.70 could be due to the fact that the 14 questions of the post-activity test cover different loose-related topics in four different areas of the island, with few questions per area, not homogeneously distributed. The Cronbach alpha for the satisfaction surveys and Likert scale-based questions is reported in the relative tables. All of them are equal or higher than.7 except for the "student's points of view" Likert scale that is equal to .63.

3.6.2. Questionnaires

Teachers: At the end of the activity, a satisfaction survey was delivered to the 58 teachers involved, aimed to know their perception and consideration about the educational path at Sustainability Hub. For phase 1, they were also asked to give suggestions about any improvements or implementation of new topics. The teachers' survey is reported in Annex 3.A2a.2. Some of the teachers' questions were very similar to the students' satisfaction survey with prompts appropriately modified. Preliminary results related to the first group of 21 teachers can be found in Occhioni et al. (2022).

The 11 teachers involved in phase 2 and phase 3 as observers were asked to monitor the students, behavior and interest during the activities with open-ended questions (Occhioni & Paris, 2021). In the 3.6.3 section, data related to the total group of 58 teachers are reported.

Students: Online questionnaires were administered to students before and after the activities. The pre-activity test consists of:

- a section related to general information about students
- a knowledge test with 14 questions, labeled T1-T14, both "Single-Select Multiple-Choice Questions" and "Multi-select Multiple-Choice Questions", and ordering.
- two multi select multiple choice questions on "specific topics", such as their perception of main global issues and the importance of waste as resources
- a 5-point Likert scale section about their digital skills and knowledge of VW

The post-activity test consists of:

- **a knowledge test of the same 14 questions**, both single-select multiple-choice Questions and multi-select multiple-choice questions. The knowledge test covered topics as georesources, environmental footprint indicator and climate change. A group of eight additional questions (six specifically related to the general introduction of Agenda 2030 and two to deepen the Environmental Footprint Indicator topics) was delivered only in the post-activity survey (F school). The questions were very similar or equal to the pre-activity survey questions
- Two multi-select multiple-choice questions on "specific topics", such as their perception of the planet main global issues and the value of waste as new resources
- **Three 5-point Likert statements on "Students point of view" about "consumption and resources".** A series of four open-ended questions about their perception on the meaning of

"being sustainable" and their willingness to act in a sustainable way were added for the F school only. The 5-point Likert scale statements and the open-ended questions aimed to understand the level of involvement of the students in the sustainability topics but also to make them reflect about the connections with the social and economic aspects of the environmental problems. The statements and the open-ended answers are reported in "Results" with the most common answers

- a satisfaction survey (5-point Likert scale and open-ended answers) related to their experience in the Sustainability Hub Island. It consists of 7 questions (5-point Likert scale). An additional question was delivered only at the W group, on eleven aspects of the use of the platform. Two Open-ended questions were devoted to suggestions/improvements

Results of the questionnaires were analyzed as described in Chapter 2. The Pre- and Post-questionnaires are reported in Annexes 3.A2a.3 and 3.A2a.4.

3.6.3. Results of teachers' satisfaction survey

Teachers were asked to evaluate the student target of this activity and most of them (81%) stated that content in the island is suitable for 11-14-year old students and 67% of them said that the Sustainability Hub island can be also used as a teaching tool for 15-16-year old students. In Table 3.A2a.5. the results of the teachers' satisfaction survey are reported.

Table 3.A2a.5. *Teachers' satisfaction survey (58 teachers). Likert scale: 1-2: Strongly disagree / disagree; 3: Neutral; 4-5: Agree / Strongly agree*

Statement	Likert scale			Median
	1-2 %	3 %	4-5 %	
The learning scenario is engaging	1.7	12.1	86.2	5
The educational pathway is consistent with the sustainability topics	1.7	12.1	86.2	4
Web resources are suitable for learning	1.7	13.8	84.5	4
The multimedia presentations and info-panels are clear and explanatory	1.7	20.7	77.6	4
On-line games are suitable for learning	1.7	12.1	86.2	4
The number of practical activities is enough to foster learning	8.6	12.1	79.3	4
Practical activities are well-structured	1.7	27.6	70.7	4
Moving through the different part of the island is easy	12.1	37.9	50.0	3.5
I've experienced difficulties with the viewer firestorm (reverse scored)	24.1	36.2	39.7	3
Learning path to follow is clearly highlighted (37 teachers)	5.4	13.5	81.1	4
Cronbach alpha = .87				

From the survey it emerged that teachers found the educational path suitable for teaching sustainability topics, appreciating the various 3D learning objects. Since some teachers experienced difficulties in the use of the viewer, it was decided to increase their preliminary training. Some suggestions included the need to better map the island's activities, mark the path to follow, but also to add more topics about recycling, georesources and their over-exploitation.

3.6.4. Result of students' knowledge test

In phases 2 and 3 (students), the knowledge gain (KG) was calculated from the difference between the post-activity and pre-activity mean test scores of each class (knowledge test with 14 questions) (Table 3.A2a.6). In total, 40 values of KG were obtained (19 related to the S-type classes), 3 related to the W-type classes and 18 related to the 9 WS-type classes (1 group S and 1 group W for each WS-type class). The mean knowledge gain for both the groups S and W were calculated and analyzed with the U Mann-Whitney test (Table 3.A2a.7). It clearly emerges that the knowledge gain of the W group is about double respect the group S and the difference between the 2 groups is statistically significant ($P<0.001$). In Figure 3.A2a.8 the boxplot of the knowledge gain values is displayed for both groups.

In addition, the absolute values of mean test score % of the pre- and post- activity tests were analyzed, to investigate if their difference was statistically significant and to compare the scores of groups S and W. The mean score of the knowledge test for all students increased from 50.5% correct answers in the pre-activity test to 65.2% in the post-activity test. Among them, the students in the S group obtained a post-test mean score of 61.8% whereas those in the W group obtained 76.4% correct answers (Table 3.A2a.8). No data of students' test scores were excluded, even if they scored less than 20% correct answers. The W group obtained a better mean test score both in phase 2 and in phase 3. Using the U Mann-Whitney test, in the 95% confidence interval, the difference between the pre-activity test and the post-activity test and the difference between the group W and S of the post-activity test are statistically significant.

In schools where there were both group S and W (schools F, N and C phase 2, Table 3.A2a.8) there is no statistically significant difference in the pre-activity mean test score between the two groups, making more significant the difference between the S and W groups in the post-activity test. The large effect size (0.98) between the total group W and S give strength to the P value. In Table 3.A2a.8 are reported the mean test score % and standard deviation for each phase and school, and the total results. N. is the number of students. Two P values are reported, the Post-Pre P value, related to the comparison of pre- and post-activity tests of each group and the S-W P value related to the difference between groups S and W.

In Table 3.A2a.9 results between grade, gender and school are reported, including the pairwise comparison of the U-Mann Whitney test. Among all the 575 students who answered the questionnaires, no significant differences were found with respect to gender. In the pre-activity test the mean score percentage for males was 50.0% and for females was 51.0% with a P-value of .333. In the post-activity test, the mean score percentage for males was 65.3% and for females was 65.2% with a P-value of .896. Regarding students' age, in the pre-activity test there is no significant difference between the scores of 11-12-year old students versus 13-year old students (P value = .597), and 11-12-year old students versus 14 (P = .271).

On the contrary, in the pre-activity test 13 and 14-year old student age groups are statistically different (P = .001), with 14-year old students scoring higher. In the post-activity test there is no significant difference in score among students of different ages (P =.378). The comparison between results of schools from different regions of Italy shows mean scores statistically equivalent, except for the school D, which showed lower results, both for the pre-activity and post-activity test.

Table 3.A2a.6. *Mean test score % and knowledge gain of each class*

PHASE	SCHOOL	CLASS	GROUP	PRE-ACTIVITY			POST-ACTIVITY			KNOWLEDGE GAIN
				N.	MEAN TEST SCORE %	STD	N.	MEAN TEST SCORE %	STD	
2	C	2Bc	S	20	46.8	16.6	17	59.7	15.4	12.9
2	C	2Ec	W	20	53.2	10.2	18	78.2	9.3	25.0
2	N	2En	S	19	48.1	12.8	19	58.3	16.9	10.2
2	N	2En	W	10	52.9	18.2	10	77.1	12.9	24.2
2	N	3En	S	15	50.0	14.3	15	58.6	16.0	8.6
2	N	3En	W	8	55.4	13.6	8	76.8	9.2	21.4
3	C	1BCc	S	18	44.8	14.9	16	65.6	12.6	20.8
3	C	3Bc	S	19	46.3	8.0	14	67.4	17.0	21.1
3	D	2Ad	S	19	41.7	14.1	14	56.6	13.0	14.9
3	D	2Cd	S	17	42.9	13.8	19	55.3	13.8	12.4
3	D	2Dd	S	25	44.0	16.1	20	65.3	10.7	21.3
3	D	2Ed	S	23	41.6	11.7	18	60.7	17.0	19.1
3	D	2Fd	S	23	44.7	14.0	22	56.8	15.3	12.1
3	F	1Gf	S	14	44.9	15.5	12	54.2	19.6	9.3
3	F	1Mf	S	22	51.6	16.9	22	66.2	17.1	14.6
3	F	1Pf	S	23	51.2	12.1	19	68.4	9.9	17.2
3	F	2Cf	S	14	54.6	14.4	13	65.4	14.5	10.8
3	F	2Lf	S	19	50.4	13.8	18	60.3	17.7	9.9
3	F	2Mf	S	20	55.0	12.9	17	68.1	19.7	13.1
3	F	3Cf	S	14	51.5	12.9	14	63.3	13.4	11.8
3	F	3Ef	S	23	53.4	12.4	19	62.4	21.4	9.0
3	F	3Lf	S	21	59.5	10.4	19	60.9	13.3	1.4
3	F	3Mf	S	26	52.5	14.4	23	63.7	17.6	11.2
3	F	3Nf	S	22	55.2	9.1	21	63.3	13.4	8.1
3	F	1Ef	S	18	52.0	10.9	9	61.9	17.5	9.9
3	F	1Ef	W	18	52.0	10.9	8	77.7	11.1	25.7
3	F	1Ff	S	19	53.0	10.7	6	59.5	10.8	6.5
3	F	1Ff	W	19	53.0	10.7	6	71.4	16.3	18.4
3	F	2Of	S	23	51.3	11.7	10	65.7	18.4	14.4
3	F	2Of	W	23	51.3	11.7	11	79.2	11.7	27.9
3	F	3Af	S	19	55.7	15.5	11	69.5	10.7	13.8
3	F	3Af	W	19	55.7	15.5	7	76.5	14.1	20.8
3	F	3Gf	S	20	53.6	16.3	11	54.5	11.6	0.9
3	F	3Gf	W	20	53.6	16.3	7	77.5	10.5	23.9
3	F	3If	S	25	50.6	11.8	13	53.3	15.9	2.7
3	F	3If	W	25	50.6	11.8	10	66.4	11.7	15.8
3	F	3Of	S	26	52.7	13.4	8	60.7	15.3	8.0
3	F	3Of	W	26	52.7	13.4	16	83.1	10.7	30.4
3	F	1Of	W	19	53.0	15.7	19	75.2	14.0	22.2
3	F	2E-2Ff	W	27	54.8	12.8	16	73.2	9.9	18.4

N. is the number of students

Table 3.A2a.7. *Knowledge gain for S and W groups*

Group	n. Groups	Knowledge gain	STD	P value (U Mann-Whitney test)
S	28	11.64	5.35	<.001
W	12	22.87	4.18	

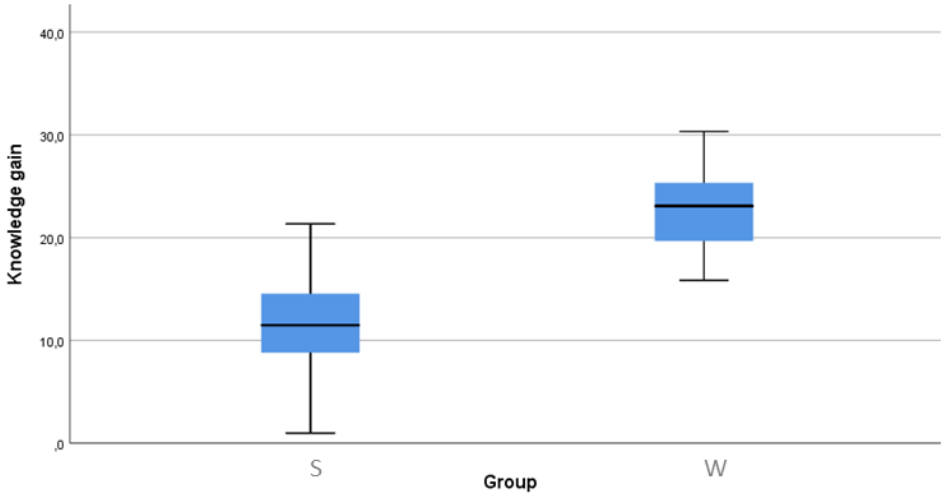

Figure. 3.A2a.8. *Boxplot of Knowledge gain*

Table 3.A2a.8. *Summary of the pre-activity and post-activity score tests for the W and S groups divided in phases and schools*

		PRE-ACTIVITY TEST			U Mann-Whitney TEST	POST-ACTIVITY TEST				U Mann-Whitney TEST	
School	Group	N.	Mean Score %	STD	P value Pre S-W	N.	Mean Score %	STD	Knowledge Gain	P value Post S-W	P value Post-Pre
						Phase 2					
C	W	20	53.2	10.2	.148	18	78.2	9.3	25.0	<.001	<.001
C	S	20	46.8	16.6		17	59.7	15.4	12.9		.020
N	W	18	54.0	15.9	.232	18	77.0	11.1	23.0	<.001	<.001
N	S	34	48,9	13.3		34	58.4	16.3	9.5		.011
						Phase 3					
C	S	37	45.6	11.7	/	30	66.4	14.6	20.9	/	<.001
D	S	107	43.1	13.9	/	93	59.1	14.4	16.0	/	<.001
F	S	414	52.9	13.2	.805	265	62.8	16.1	9,8	<.001	<.001
	W		52.9	13.2		100	75.9	12.5	23,0		<.001
						Total					
	S	650	50.5	13.9	/	439	61.8	15.7	11.3	<.001 Effect size d = 0.98	<.001
	W		50.5	13.9		136	76.4	11.9	25.9		<.001

Table 3.A2a.9. *Results by gender, grade and schools and pairwise comparison*

		PRE-ACTIVITY TEST			U Mann-Whitney TEST	POST-ACTIVITY TEST			U Mann-Whitney TEST
School	**Group**	**N.**	**Mean Score %**	**STD**	**P value Pre**	**N.**	**Mean Score %**	**STD**	**P value Post**
					Total by gender				
	Male	314	50.0	13.8	.333	292	65.3	16.6	0.896
	Female	336	51.0	13.9		283	65.2	15.7	
					Total by grade				
	K6	133	50.4	14.0	.001	117	67.1	15.6	0.378
	K7	279	48.5	14.3		242	64.4	16.2	
	K8	238	53.0	12.9		216	65.2	16.3	
					Pairwise comparisons of grades				
	K7-K6				.199				/
	K7-K8				<.001				
	K6-K8				.090				
					Schools				
C		77	47.9	13.1	<.001	65	67.9	15.1	<.001
D		107	43.1	13.8		93	59.1	14.4	
F		414	52.9	13.2		365	66.4	16.3	
N		52	50.7	14.3		52	64.8	17.1	
					Pairwise comparisons of schools				
D-C					.016				.002
D-N					.002				.201
D-F					<.001				<.001
C-N					0.394				.240
C-F					.005				.394
N-F					.180				.484

3.6.5. Specific topics (phases 2 and 3)

Table 3.A2a.10 reports the analysis of single or grouped questions of the knowledge test, especially those related to georesources (water, soil, critical minerals, fossil fuels) and their environmental footprint indicators, as well as the multi-select multiple-choice questions (e.g. “What are the main global issues humanity has to face” and “Resource or Waste?”). The answers to questions related to the knowledge test are expressed in % of correct answers, while the multi-select multiple-choice questions are expressed in % of responding students. In Table 3.A2a.9 the Post-Pre P values and the S-W P values are also reported.

Table 3.A2a.10. *Analysis of the results regarding the specific topics*

n.	Topics	Pre activity	Post activity			Difference		Chi-Square test / U Mann-Whitney test	
		Total students	Total students	W Group	S Group	Post-Pre	W-S	P Value	P Value
		650	575	136	439			S-W	Post-Pre
1	**Environmental issues. Students' perception (% answers on total responding students)**								
a.	Climate change	64.2	82.3	84.6	81.5	18.1	3.1	0.422	<.001
b.	Loss of biodiversity	62.9	60.3	65.4	58.8	-2.6	6.6	0.165	0.355
c.	Lack of drinking water	62.6	72.5	73.5	72.2	9.9	1.3	0.763	<.001
d.	Overexploitation of natural / mineral resources	36.9	55.1	55.9	54.9	18.2	1	0.840	<.001
2	**Resource or Waste? (students' perception) (% answers on total responding students)**								
a.	Water	95.8	95.3	94.1	95.7	-0.5	-1.6	0.454	0.645
b.	Minerals / Rocks	73.1	76.2	85.3	73.3	3.1	12	0.004	0.214
c.	Soil	50.9	73	76.5	72	22.1	4.5	0.303	<.001
d.	Recyclable waste (metals. glass. plastics)	31.7	48.5	50.7	47.8	16.8	2.9	0.554	<.001
e.	Organic waste	24.2	48.2	44.9	49.2	24	-4.3	0.375	<.001
f.	Waste from Electrical and Electronic Equipment (WEEE)	5.8	36.9	30.9	38.7	31.1	-7.8	0.098	<.001
3	**Georesources (% of correct answers)**								
a.	Non-renewability of soil	47.2	71.8	85.3	67.7	24.6	17.6	<.001	<.001
b.	Fossil fuels and their influence on global warming (Group of 7 questions)	59.9	67.6	76.6	64.8	7.7	11.8	<.001 (U Mann)	0.05 (U Mann)
4*	**Environmental footprint indicators (% of correct answers) (Group of 5 questions)**								
a.	Definition and meaning	54.7	64.6	73.2	61.3	9.9	11.9	<.001 (U Mann)	<.001 (U Mann)
5	**Concept of water footprint (% answers on total responding students)**								
a.	Related only to the consume of fresh water	55.7	35.1	26.5	37.8	-20.6	- 11.3	<.001	<.001
b.	Related to the entire production chain of goods (concept of hidden water)	31.2	56.5	71.3	51.9	25.3	19.4	<.001	<.001
6	**Definition of sustainable development (% answers on total responding students)**								
a.	Related only to environmental issues	57.7	36.3	22.1	40.8	-21.4	- 18.7	<.001	<.001
b.	Related to the need of present and future generations (environmental. social. and economic issue)	37.5	59.0	74.3	54.2	21.5	20.1	<.001	<.001
7*.	**Agenda 2030** **(Group of 6 questions)** % of correct answers	/	72.5	81.2	69.2	/	12	<.001 (U Mann)	/

*Notes: *The items 4 and 7 are referred to the students from F school only (414 total students. responding students 365 = 88.2%).*
P values refers to the Chi square tests except items 3.b.,4. and 7.
P value S-W refers to the comparison between the groups S and W in the post-activity test.
P value Post-Pre refers to the comparison between the post-activity and pre activity mean test score (total students)

Environmental issues (Topic n.1, Table 3.A2a.10)**:** Although before the activity, the overexploitation of natural/mineral resources was much less perceived as an important issue by students, in the post-activity questionnaire the number of students who were aware of this issue increased, passing from 36.9% to 55.1%. However, this issue appears to be less perceived as important with respect to other environmental issues, such as global warming. This is probably due to the little attention given in Italian schools to mineral resources and their practical applications (Occhipinti et al. 2016).

Resource or Waste? (Topic n.2, Table 3.A2a.10)**:** The answers show that it was clear to students that some georesources, such as water and minerals are important resources (respectively 95.8% and 73.1%), compared to soil or waste (respectively 50.9% and less than 32%). In addition, there is no significant difference between answers in pre-activity and post-activity surveys. On the contrary, after the activity about recycling and circular economy, the potential of waste as a source of useful materials was recognized by a higher percentage of students (+16.8% for recyclable waste, +24.0% for organic waste, and +31,1% for WEEE).

Georesources (Topic n.3, Table 3.A2a.10)**:** Regarding the loss of soil and its non-renewability (in the short term), it is interesting to note that, after the activities in the "Sustainability Hub" island, W students are more conscious of soil as a non-renewable resource (+38,1%), therefore leading to the concept of its protection and preservation. In comparison, before the activities students seem to be more aware of the role of fossil fuels as georesources and, at the same time, about their negative influence on environmental parameters (CO_2 level and temperature) related to global warming (59.9% before the activity).

Environmental footprint indicators (Topic n.4-5, Table 3.A2a.10)**:** The results show an increase of the mean score in the post-activity test, especially regarding the acquisition of consciousness that water consumption is not only related to fresh water, but also to water used in production processes of goods and products, especially for the W group (+40.1%).

Definition of sustainable development (Topic n. 7, Table 3.A2a.10): In the post-activity test there is a strong increase of correct answers with respect to the pre-activity test, especially for the W group, demonstrating that the information of the students regarding this topic is still limited, and the activity was useful to inform the students (+36.8 for the W group).

Agenda 2030 (Topic n.6, Table 3.A2a.10)**:** Regarding this topic, a significant difference between groups S and W emerges, with the W group scoring higher (+12%). In the S group the Agenda was explained through the avatar mediation, whereas in the W group the students explored the Hub area and interacted with documents and 3D objects, which probably contributed to increasing their level of attention towards the topic.

3.6.6. Students' point of view (phases 2 and 3)

The students' points of view about sustainability topics were investigated, using the evaluation of the F school's open-ended questions (Table 3.A2a.11). Answers were grouped by text analysis, taking into consideration the first four responses in order of frequency, for each question, to obtain a general view of the students' perceptions and personal ideas. The answers demonstrated the students' consciousness towards the exploitation of georesources, the importance of recycling, the use of renewable energy, as well as the awareness about the need of individual contributions by the citizens to sustainability, by adopting a greener lifestyle. In Table 3.A2a.12, a group of three questions aims to learn about the students' perception of the individual role of citizens in avoiding over-exploitation of resources. The value 4 for the Likert scale median means they take into account this issue.

Table 3.A2a.11. *Summary of the students' Points of view - open-ended questions. Questions a., b., c., and d refer to F school (365 students). Percentages are relative to the number of students giving that answer on the total students. The frequency was obtained via text analysis*

	Question / Statement	Responses	%
a.	What is, in your opinion, the meaning of acting in a sustainable way?	Respect/safeguard the environment/planet	53.4
		Save resource/materials and simplify lifestyle	11.8
		Recycle/reduce plastic	10.7
		Lower pollution/reduce greenhouse gasses	10.7
b.	Indicate 3 practical actions you are ready to carry out immediately to modify your lifestyle towards sustainability	Recycle/reduce plastic	72.9
		Water saving	34.0
		Sustainable public transportation	28.5
		Energy reduction	15.1
c.	Indicate which characteristics, in your opinion, an ideal sustainable city should have	Recycle/plastic reduction	42.7
		Sustainable transportation	34.5
		Reduce industrial pollution and greenhouses	22.2
		Use renewable energies	18.1
d.	Indicate which actions are effective to save energy or limit greenhouse gasses.	Increase glass, plastic and metal recycling	81.1
		Increase urban greenery	76.2
		Improve public transportation	71.8
		Use better insulation for buildings	68.8

Table 3.A2a.12. *Summary of the students' Points of view - Likert scale statements (Likert scale 1 = Strongly agree, 2 = Agree, 3 = Neutral, 4 = Disagree, 5 = Strongly disagree). Questions refer to all students (575).*

Perception of individual role in avoiding resource overexploitation		Cronbach alpha	Likert scale %			Median
		.63	**1-2**	**3**	**4-5**	
a.	The Earth's population is increasing rapidly. but this is not a problem because resources are sufficient for all		9.6	20.0	70.4	4
b.	It is not necessary to reduce consumption and simplify lifestyles. Resources are enough for all		3.3	10.1	86.7	4
c.	The contribution of a single person is minimal towards the importance of environmental issues. Any personal effort is useless		9.1	10.6	80.3	4

3.6.7. Students' satisfaction survey

Findings about the learning experience of students and the quality of the learning scenario are shown in Annex 3.S.2. The Likert scale survey allowed the evaluation of the learning experience and the quality of the learning scenario between the S and W groups. Students in the W group demonstrated a better learning focus, and higher knowledge acquisition and level of engagement in the activities with respect to the S group Students of phases 2 and 3 appreciated the 3D educational items and information presented in the Sustainability Hub, with no statistical difference between the groups S and W. On the contrary, the W group judged the learning experience, the organization of the educational path, and the graphic elements better than the S group (P value <.001).

Students were also asked to say if virtual worlds give advantages in education and distance learning (open ended questions). This topic is developed in Chapter 3.S.

In Figure. 3.A2a.9 and 3.A2a.10 students' suggestions for improvements and new sections are reported (group W). About 30% of the students stated that no improvement is necessary; about 40% gave suggestion about improve some technical issue of the viewer (dependent by the software house), and improve the graphic design. Regarding the new section they would to implement in Sustainability Hub, about 30% gave suggestions (a video area, a section to exhibit students work, or a collection of sustainable actions the willing to do, some topics such as urban sustainability, recycle, water – already hosted in other islands).
Other considerations about students' satisfaction are reported in section 3.S where a global overview of the students' satisfaction of the entire research is displayed.

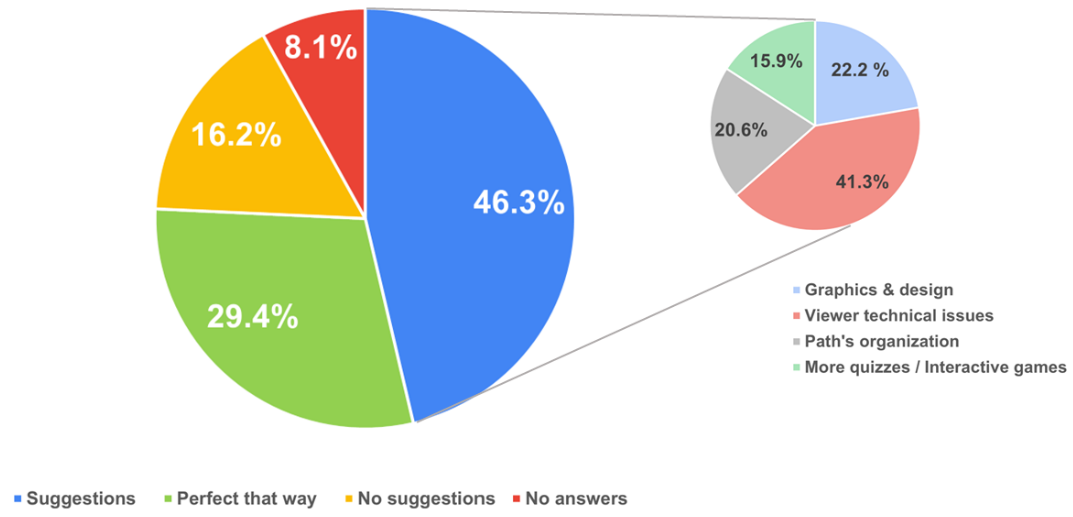

***Fig. 3.A2a.9**. Students' suggestions for improving Sustainability Hub. Group W*

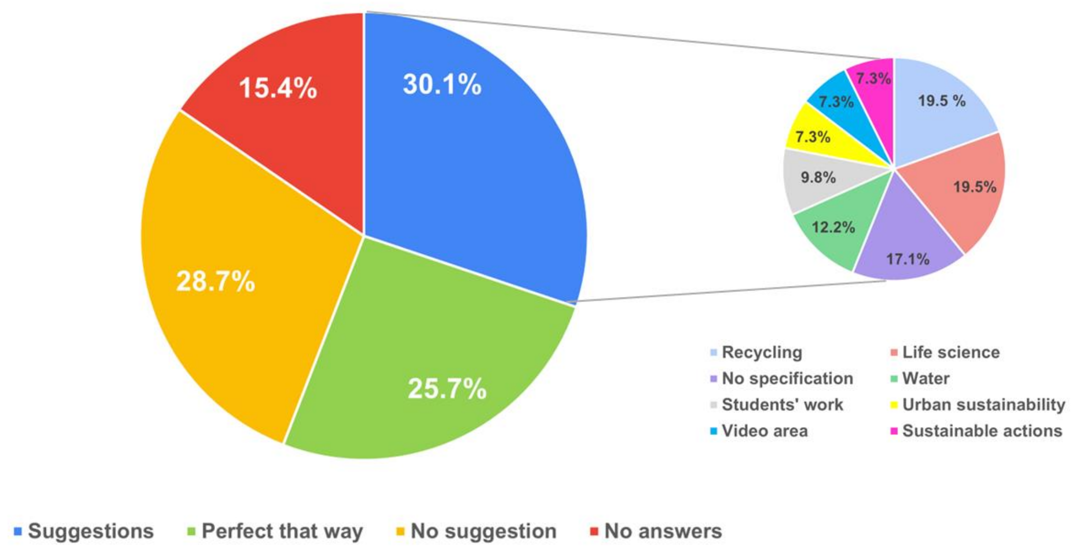

***Fig. 3.A2a.10.** Students' suggestions for the development of new sections. Group W*

3.6.8. Monitoring activity

Teachers' monitoring questionnaires aimed to evaluate, from a didactic point of view, the interest, motivation, and sustainability awareness of students. Therefore, they observed their students during the online activities and collected their feedbacks in the days following the experimentations. Table 3.A2a.13 summarizes some open answers given by the 11 teachers involved in this part of the experimentation. In teachers' opinion, students showed an enthusiastic motivation and participation during the activity and a high interest on sustainability topics after the activity itself. In addition, teacher's questionnaires showed that virtual worlds facilitated a high level of engagement and the perception of "closeness to classmates during lockdown periods". This aspect was very much appreciated and evaluated as very useful for the student-student and student-teacher social interaction in the difficult lockdown period.

Table 3.A2a.13. *Teachers' monitoring questionnaire open answers*

Question	Answers	%
Do you think activities in virtual worlds helped students feel near their classmates during the lockdown?	Yes	90.9%
	No	9.1%
How was the students' motivation and participation	Not different respect to the normal school activity	9.1%
	Good	27.4%
	Enthusiastic	63,4%
Did you notice a greater interest of students in sustainability topics after the virtual activity?	Yes	54.5%
	No	9.1%
	Not enough time to have feedback	36.4%
Advantages	No advantages	9.1%
	students feel near their classmates	90,9%
	Ideas can be experimented immediately	9.1%
	Meet student's needs / students are protagonist of their learning	18.2%
	Interaction	18.2%
	Approach to science by game	18.2%
	Environment is suitable to express creativity and useful as repository	9.1%
Disadvantages	No disadvantages	36,4%
	The need of a desktop or laptop PC	45,4%
	There is the risk that students don't recognize the activity as educational but tend to accomplish mission in a hurry as in a videogame.	9.1%
	The lack of hands-on activities	9.1%

3.7. DISCUSSION

Teachers' comments and students' questionnaires demonstrated that this educational activity was effective at approaching the theme of sustainability in an engaging way. Teachers were very interested in the activity and judged the Sustainability Hub as a valid tool to teach sustainability for 11-14-year old students, evaluating positively the educational path, the pleasantness of the learning scenario, and the quality of content proposed. They appreciated the possibility to carry out practical activities, especially during the Covid-19 school lockdowns, and the interdisciplinary content made available for each theme. They also found the online games useful to stimulate the students' interest and engagement. Teachers declared it was a stimulating way to propose practical activities to their students, and it could be also easily adaptable to older ones.

We improved the island and tuned the educational path with the help of some suggestions from teachers. For instance, they enhanced the indications to more easily find resources to be consulted to answers questions and acquire badges. Also, some teachers suggested increasing the space dedicated to georesources and circular economy, as an important issue in the EU Green Deal (Fetting, 2020). Some topics were already present in the connected islands that were not visited by students and teachers due to the short time devoted to the experimentation, but others were added, such as new online and interactive games about georesources and carbon and water footprint. Therefore, Sustainability Hub now has the potential to be used as an educational tool during the school year to also approach other geoscience topics. Results from phases 2 and 3 show that the activity, although brief, contributed positively to increasing the students' knowledge about sustainability. The high number of correct answers of the post-activity test testify that the vast majority of the students become more aware of many aspects of the sustainability issues raised by the Agenda 2030 and the SDGs (Table 3.A2a.10, Specific Topics)

Also, the better results obtained by the W group evidenced the efficacy of the VW to involve students, especially when they can be personally involved with their avatars in the world despite the distance-learning mode and the difficult situation related to Covid-19 school lockdown. Gamification elements in an Opensimulator-based VW engage students more, with respect to non-game-based VW (Heesung & Fengfeng, 2016). In fact, the values of the knowledge gain reported for the groups W and S are very similar to the study reported by Rosmansyah et al. (2019) using a gamification approach. Also Farra et al. (2013), reported a significant difference in learning retention between a VW group and a web-based learning group.

The statistical equivalence or slight difference in results as a function of students' age could be explained by the general interest demonstrated by the students for environmental themes and the beginning of the new transdisciplinary mandatory curriculum of Environmental Education, where the main concepts of sustainability were introduced in all school grades in the same year.

Still, the reason why geoscience topics (e.g. the overexploitation of natural/mineral resources) are less perceived with respect to other environmental issues (Topic n.1, table 3.A2a.10), can be related to the little time devoted to geosciences in Italian schools, considerably less than Chemistry and Biology (Realdon et al.,2016).

Moreover “In Italy, as in many other countries, the feeling of pupils, students, and even common people towards Earth sciences is strongly conditioned by the idea that Geology is only concerned with ‘stones and catastrophes’” (Occhipinti et al.2016).

However, activities in the Sustainability Hub changed students' their perspective (Topic n.2 and 3, Table 3.A2a.10), increasing their awareness, especially regarding the reuse/recycle of waste, stressing the role of Waste from Electrical and Electronic Equipment to recover metals and rare earth elements, or evidencing the importance of using organic waste to produce bioplastics.

The environmental footprint indicators were introduced to assess the impact of human activities on the planet. In the Sustainability Hub, students dealt in a practical way with these indicators, calculating their personal footprint. Group W calculated their own footprint instead of following an instructor, and this likely resulted in better scores than the group S, in the post-activity knowledge test for that topic (Topic n.4-5, Table 3.A2a.10).

One of the important topics of the project, acquired by students thanks to the activities carried out, is the consciousness that sustainable development is not only related to environmental issues but also takes into account the economic and social needs of the present and future generations (Topic n.6, Table 3.A2a.10), as stated by the United Nation document “Transforming our world” (UN, 2015).

The students' point of views (Table 3.A2a.4) highlighted that recycling and recovering useful materials, plastic reduction, and increasing sustainable transportations are well-established concepts, since they were indicated as important by many students and in the majority of answers. These are followed, to improve sustainability, by the suggestions to improve urban greenery, reduce water consumption and better insulate building. However, most of the answers to the question "What is, in your opinion, the meaning of acting in a sustainable way?" were somewhat superficial, generally mentioning respect for the environment or safeguarding the planet without providing specific examples.

However, when answering the question “Indicate which characteristics, in your opinion, an ideal sustainable city should have”, it is interesting to note that about 8.5% of pupils declared that a sustainable city should pursue targeting the social objectives of the Agenda 2030, such as the reduction of hunger, poverty, inequality and an increase in well-being, health and education. Although this percentage appears small, it can be considered a surprisingly good result. These topics were not addressed during the experimentation. Despite this, the students considered mutual aid and volunteering to be important, showing they have well understood the three pillars of sustainability: economic, environmental and social.

Students understood the importance of topics generally related to the concept of overexploitation of the planet's resources (Table 3.A2a.9) and how it is important to simplify their lifestyle. They had a generalized awareness that good behaviors by individuals are important, being conscious of the role of citizens as promoter of sustainable consumption and production (SDG 12) (UN, 2015).

Regarding the students’ experience in the VW, a high degree of satisfaction emerges from the student questionnaires and from the comments of the teachers who acted as observers during the online activities. The students appreciated the quality of the scenario and the interaction with 3D objects, which helped them to better understand the content proposed (Christopoulos et. al, 2014). The high level of interaction with the VW objects and the students’ strong engagement in the activity were testified also by the number of the badges collected at the end of each area: for the W group, 66.7% of badges were collected at phase 2 and 78.8% at phase 3.

The UNESCO learning objectives listed in Chapter 1 were investigated primarily in the cognitive domain, due to the short time devoted to the activity for each group of students. Some aspects of the behavioral domain were addressed as willingness of students to adopt sustainable lifestyles. Each competence was associated with a group of questions / point of view of the pre / post knowledge test. The increase of knowledge gain for specific questions (as in Table 3.A2a.10) testify that, at the level of cognitive domain, competences were achieved, especially for the W group. The game-based learning approach and the engagement in the virtual world helped students to likely achieve those competences.

Nevertheless, the results of the experimentation demonstrate that the activities were effective for both groups participating, as they increase their knowledge. Moreover, the higher scores obtained by the W group, indicate the efficacy in using virtual worlds in e-learning teaching, useful in this case of lockdown periods. In normal school time, however, this activity can be proposed to the students as a practical task in the computer laboratory, as an extra-curricular activity to do at home or even in the frame of a project to include also acquisition of ICT skills.

3.7.1. Limitations

A limitation of the applicability of this educational tool during the COVID-19 lockdown period was determined by the large number of pupils forced to use tablets and mobile devices (not compatible with Opensimulator) instead of the school or home PCs. For that reason, the number of students in the S group was triple with respect to the W group. The PC unavailability was due also to different reasons such as the sharing of devices among siblings for online lessons, the hardware requirements of personal computers and the preference of families to buy smartphones and tablets for distance learning. The PC inaccessibility still represents a weak point to consider when implementing these kinds of activities at home instead of in the school computer laboratory.

Students who accessed the world had a good experience in terms of usability and enjoyment, and they had no difficulties in dealing with the structure and tools of VW. On the contrary teachers, although very interested, showed a digital divide with respect to the students, to be taken into account. Students are used to playing games, and this puts them in the position of taking full advantage of using VW platforms for learning.

In comparison, teachers needed more practice to master the change to VW or, in some cases, to be introduced to the VW. However, these practical problems were solved by increasing the time devoted to training for teachers.

3.7.2. Implications

The Sustainability Hub is now available for Italian schools, with educational paths and islands ready to use for teaching many geosciences and sustainability topics. Work is in progress for a translation into English, useful for students of other countries as well as for Italian students to improve their English language knowledge in the frame of CLIL activities (Content and Language Integrated Learning), widely used in Italian high school. By using the VW, Italian schools had the opportunity to approach topics relative to the new course of Environmental Education during the Covid-19 pandemic in an engaging way. The use of avatars also allowed interactions with and between students, which was useful to support their social needs in a time of crisis.

Ranieri (2021) stated that, during the Covid-19 school lockdown, Italian teachers "kept on applying their usual pedagogy and books" as a sort of a simple digitalization of a traditional lecture. VW and activities such as those carried out in the Sustainability Hub island can also represent an added value to classic lessons in person (teachers can show the island using an interactive whiteboard or an interactive monitor), although the gamification approach is preferred because of the better outcomes. Students can explore selected topics on Sustainability Hub in the computer lab, as an online lab experience. However, it is possible to plan long-term projects, deepen specific topics in the other islands directly reachable from Sustainability Hub, or asking students to add new content. Based on the teachers' and students' needs, Sustainability Hub can be modified by specific users (e.g. teachers or students under the supervision of teachers) if properly authorized by the managers of the island (the authors). If necessary, content of Sustainability Hub is also available as multimedia presentations to be delivered to the students outside the VW, as support to the traditional lessons.

Future work aims to include more interactive activities, increasing the time necessary to explore each area, and improving the possibility to increase students' assessment by adding specific 3D objects and links to online forms. The satisfactory results obtained until now also lay the foundations for planning more articulated and in-depth thematic paths, useful for older students.

3.8. CONCLUSIONS

This project shows how Opensimulator-based virtual worlds can be an effective platform for schools to engage students in explorative and collaborative activities, giving them also the perception of “being there and together”. During lockdowns, or as a support to the traditional teaching, this method can be used as “lab activity” with interesting and promising results, suitable for any type of subjects and open to interdisciplinary topics. The experimentation carried out on many students and their teachers indicate that there is high interest in using virtual worlds which can help both in increasing the interest in STEM and improve digital and transversal skills.

A video about Sustainability Hub island can be seen at:

https://www.virtualscience.it/video/sustainability_hub_EN.mp4

3. A2b. Sustainable City Game

Figure 3.A2b.1. *Summary of the project*

This section reports the results obtained from the experimentation of the activity "Sustainable City Game", carried out with the colleague Alessandra Beccaceci. The paper is in preparation to be submitted to Rendiconti online della Società Geologica Italiana and it is reported here in the same form.

SUSTAINABLE CITY VIRTUAL GAME: HOW TO ENGAGE STUDENTS IN SUSTAINABLE LIFESTYLES

A. Beccaceci[1], M. Occhioni[1], E. Paris[1]

[1]School of Science and Technology, University of Camerino, Italy. Corresponding author email: alessandra.beccaceci@unicam.it

ABSTRACT

The Sustainable City Game (S-City Game) was created to approach the United Nations Agenda 2030 and Sustainability topics. A cardboard version, already tested, has been translated as a digital version, for on-line school activities. This educational game aims to increase students' awareness about a more sustainable lifestyle, encouraging them to take actions towards a responsible management of planet resources. The S-City virtual game has been created in a virtual world based on the 3D Opensimulator platform that can be accessed by teachers and students as avatars. Virtual worlds can offer new possibilities for education, teaching and learning formats and it was evident especially during COVID-19 pandemic, when most Italian schools adopted distance learning. In fact, S-City digital game, hosted in the Techland virtual world, allows students to investigate, in an active way, topics like water saving, carbon footprint, ecological rucksack, circular economy and waste reduction, starting from daily routine actions, like eating and dressing. The game is planned to be played by K6-K10 level students. A multidisciplinary approach is used, with inputs from several disciplines, to have a holistic vision of the Sustainable Development Goals (SDGs). The game has been tested both with teachers and students, and the results are very satisfying in terms of involvement of students as well as teachers' interest. Students and teachers declared that it is an effective and engaging educational tool to vehicle the key principles of Sustainability and good practices in everyday life. This gaming approach allows students to acquire knowledge and key competences of sustainable behaviors and active citizenship for eco-friendly lifestyles and to develop problem-solving attitude and digital skills.

KEYWORDS: Agenda 2030, Sustainable Development and lifestyle, Geoscience education, educational games, virtual worlds

INTRODUCTION

The essential role of Education for Sustainability

The biosphere is an intricate system of relationships, where small changes in one context cause chain reactions in many other areas. Although for a long time human beings have suffered the effects of complex dynamics and changings of environment, today human activity has become a central element in the characterization of these alterations (Butera, 2021). Not by chance, the present geological time has been named "Anthropocene" (Crutzen, 2006), to stress a phase of global history during which the actions of human beings are the principal cause of modification in planetary balances. From the middle of the 20th century to the present day, in fact, the rate of environmental changes caused by anthropogenic factors - including atmospheric concentration of CO_2 and other greenhouse gasses, ocean acidification, tropical forest and biodiversity loss - began to increase exponentially. Therefore, this period of time could be separated from the previous ones because of the human activity impacts on Earth that overcome those caused by natural processes (Gaffney & Steffen, 2017). Humans, because of their lifestyles, seem to have forgotten to be not an isolated species, separated from the environment. We are integrated with it, an integral part of the wider biosphere of Earth. Our impact on the planet is complex and rich in interconnected factors. The ways we produce and consume, move and organize urban and rural areas, develop energy and distribute it, cause a devastating impact on ecosystems and, consequently, on our well-being and our ability to survive. Among the several aspects of sustainable development, the link between human health and planetary health has an essential value. Therefore, the field of planetary health is not only about environmental science, but is cross-disciplinary, drawing on knowledge, literature and methodologies from geology, economics, ecology, anthropology, geography and politics (Cole, 2019).

The resources overexploitation issue and, more in general, the effects of human activity on Earth balance have been known for a long time. In fact, since the beginning of 1800, scientific publications have highlighted that as living standards improved and the population increased, resources could become more and more limited (Malthus, 1826) and the environment so stressed by human activities that Earth's system would collapse. The “planetary boundaries'' concept was proposed by Rockstrom et al. (2009) as quantitative limits within humanity can continue to develop and prosper, keeping the Earth system in a certain state of balance and stability. Overcoming them increases the risk of generating irreversible environmental changes. Among the processes that affect these limits there are, for example, climate change and ocean acidification, global use of freshwater and land use change.

Looking at this global scenario, education has a key-role in a social transformation process, in the way of thinking, acting and living. The United Nations Decade of Education for Sustainable Development (2005-2014) sought to mobilize the educational resources of the world to help create a more sustainable future. Education for Sustainable Development (ESD) empowers learners of all ages with the knowledge, skills, values and attitudes to address the interconnected global challenges we are facing, including climate change, environmental degradation, loss of biodiversity, poverty and inequality (UNESCO, 2019). Learning must prepare students and learners of all ages to find solutions for the challenges of today and the future. Education should be transformative and allow us to make informed decisions and take individual and collective action to change our societies and care for the planet. The world needs students who are able to understand how every human activity affects the social and environmental context and vice versa, developing plans of action that could improve the quality of life with a positive impact on the planet. Here the indispensable role of education for sustainability that is an integral part of the Italian school curricula nowadays. Citizenship education has become a mandatory discipline for all Italian schools and one of its three key-topics is exactly the Agenda 2030 for Sustainable Development.

The Agenda 2030 and its 17 Goals and 169 targets is an international plan of action aimed to achieve global peace, justice and equity fighting hunger, poverty and environmental degradation (UN, 2015). This agreement is based on the five pillars of Sustainability: People, Planet, Peace, Prosperity and Partnership. The multidisciplinary and the connection with daily life of sustainability topics teaching need didactic activities based on active learning and interdisciplinary approaches. If the task of education is to train aware citizens of the present and future world in the name of sustainability, the learning necessarily has to be constructive and participatory.

Geoscience topics represent the key to approach environmental and sustainability issues, such as climate change, water and air pollution, georesources exploitation, and energy. In fact, Geosciences address students to complex topics, accompanying them to deepen environmental problems of the area they live in. Therefore, it is important to use these connections and improve Geoscience teaching in order to acquire valuable knowledge as well as developing skills of active citizenship and increased environmental awareness.

Gamification to foster learning about sustainability

Nowadays, it is understood that in order to deal with and engage in sustainability, more is needed than just knowledge concerning sustainable development (Tilbury & Wortman, 2004). Education for sustainability demands approaches and learning environments promoting and facilitating the development of system thinking and learning for complexity of the social, economic and environmental areas.

Digital games can highly benefit learning for complexity (Fabricatore & Lopez, 2012). One of the fundamental challenges of ESD is its goal to integrate science, social sciences and managerial science into one overarching system thinking framework (Dieleman & Huisingh, 2006). This is basically a cognitive challenge that is fundamental. We are used to learning new concepts, taking things apart, deconstructing and analyzing them. We usually focus more on the parts than on the whole. On the contrary, sustainable development requires us to understand the effects of one dimension on the other dimensions and on the whole. However, since we are so poorly equipped to think in terms of "systems" and to comprehend systems behavior, we are tempted to deconstruct systems and to analyze the single parts separately. One of the key challenges of ESD education is to develop a 'systems thinking language.'

Playing games is an appropriate activity in the context of learning for sustainability, especially in the context of experiential learning that helps approaching the complexity of the world. When one plays games, one simulates and creates realities with all their complexity, mutually accepting rules, roles, conditions and assumptions. When one plays games, one can easily 'take the role of others' and develop an emotional understanding of why others act as they do. The beauty of playing games is that one 'learns by doing' and 'learns by failing' without negative consequences for the real world. One can simulate certain realities, play, manipulate and experiment and experience what the consequences are or what they might be.

An educational game prompts students to acquire new knowledge and skills thanks to an engaging and funny approach. A ludic activity always represents an involving and challenging experience to catch pupils' attention and motivation. Students are intrinsically motivated to learn, so they not only learn more, but also have a more positive experience (Chan & Ahern, 1999). Setting Educational Game (EG) has a great potential to support immersive and emotional learning experiences (Paras & Bizzocchi, 2005). Games represent an effective learning environment: they are active experiences and they are able to provide intrinsic motivation. Pupils critical thinking is incorporated both in game core mechanics and in the creative experience of the game world.

According to Lee and Hammer (2011), games are motivating because of their impact on the cognitive, emotional and social areas of players; and so, gamification in education should also focus on those three areas. In the cognitive area, a game provides a complex system of rules along with a series of tasks that guide players through a process to master those rules. The impact on the emotional area works mainly around the concept of success and failure (Domìnguez et al., 2013). On one hand, when players complete tasks, they are expected to have positive emotions by their mere fact of overcoming difficulties. Games try to assure and increase those feelings with reward systems that give immediate recognition to players' success, awarding them with points, trophies or items on task completion (Dominguez et al., 2013). On the other hand, when players fail, they can try again until they are able to overcome the tasks; a little feeling of anxiety can drive the players, motivating them. When multiple players interact through the game, these interactions have an impact on players' social area. Digital games offer a wide range of multiplayer interaction mechanisms which are integrated in the rules of the system. These mechanisms make it possible for players to cooperate helping each other towards a common goal, or just to interact socially by talking and writing.

Why an educational game about a sustainable city? More than half of the world's population now live in urban areas, and over 70% of the global population are expected to live in urban areas by 2050. According to Abu-Rayash and Dincer (2021) the importance of cities is also expected to increase due to the role of metropolitan areas as growth centers of the emerging sustainable economy. Furthermore, cities play a dominant role in global consumption, production and pollution. For this reason, sustainable cities and aware citizens' lifestyles have been identified as a key for Sustainable Development and climate change. Players cover the role of citizens in a smart city, so they have to acquire lifestyles and behaviors in line with sustainability principles.

Play games in virtual worlds, precious didactic tools for distance learning during COVID-19 pandemic.

Virtual worlds are digital spaces accessible by users in the form of avatars (a digital representation of one-self) using a user graphical interface, called viewer (Schroeder,2008). Since the beginning, educators have explored their great potential to foster learning (Littleton & Bayne, 2008; Allison & Miller, 2012) using constructivist methodologies like cooperative learning and learning by doing (Gul, 2012). A virtual world is a "metamorphosis" of our world, with people, objects, places, and providing various forms of interaction between these objects and people, represented by avatars (Bailensons, 2008). Since then, it became clear to teachers and researchers that virtual worlds can offer new possibilities for education, teaching and learning formats. In particular, the 3D platform Opensimulator (opensimulator.org) offers interesting features to support these methodologies (Dalgarno & Lee, 2010). One of these features is the interactivity. It is possible to give behavior to the objects by inserting programs in LSL (Linden Script Language) with a special editor embedded in the viewer (http://wiki.secondlife.com/wiki/LSL_Portal). Objects can move, change size and color, become transparent. Furthermore, they can give notecards, images and interactive menus with multiple choices and can link to external web resources. In a virtual scenario it is possible to explore educational paths, role play or take part in an educational game as S-City Game. Moreover, to avoid the spread of the COVID-19 crisis, many countries worldwide have temporarily shut down their schools. National and international closures affect over 91% of the education community of the world. E-learning is the only effective manner for schools to coordinate the learning process during the global lockdown and quarantine period. Many schools have instructed their students through remote learning technologies to face the effect of local closures and promote the continuity of the education process. Therefore, virtual environments could represent an effective digital tool to engage students in a participatory and active manner, despite the distance learning.

The S-City game as an educational tool for sustainability topics

The S-City Game is an educational game, created to approach the UN Agenda 2030 and sustainability topics, in order to increase students' awareness about a more sustainable lifestyle. Through deepening knowledge about exploitation of georesources, clean energy, responsible consumption and production, actions for climate, sustainable cities and communities, they are encouraged to take action towards a responsible management of planet resources.

It is planned to be played by K6-K10 level students, in teams or individually. Starting from pupils' daily routine actions, like eating and dressing, the game allows them to investigate topics like water saving and carbon footprint, ecological rucksack, circular economy and waste reduction, using a multidisciplinary approach, with inputs from several disciplines, which allows to have a holistic vision of the SDGs. In fact, the game's unique feature is that quizzes and tasks address sustainability in an interdisciplinary manner, dealing with topics of History, Geography, Science, Math, Technology and Citizenship, interconnected with each other. This game characteristic offers a multi and interdisciplinary view of the five pillars of sustainability and links also to Literature, Foreign Languages and Art topics. The questions allow pupils to reflect about simple but effective actions to take in their everyday life for increasing environmental sustainability.

The first version of S-City Game is a cardboard game, planned to be played by four teams at school. Each team has an itinerary to follow in steps, to reach the heart of a sustainable city, starting from a conventional city. The itinerary includes individual and team challenges as disciplinary multiple-answer quizzes and mini-games.

During the COVID-19 pandemic, most Italian schools have adopted distance learning. Therefore, a digital version of the game has been created in a virtual world based on the 3D Opensimulator platform that can be accessed by teachers and students as avatars. The game resides in a virtual island, the Sustainability Hub (Occhioni & Paris, 2021) where an educational path about sustainability has been developed using 3D interactive learning objects, online web games, multimedia presentations and external web resources. This island is part of the virtual world Techland, focused on Math and Science (Occhioni, 2017). Moreover, a digital game inside a virtual world allows students to train and improve digital skills, according to the guidelines for Citizenship Education in Italian schools (MIUR, 2019).

Finally, the didactic activity was planned to verify if a geoscience-related activity could improve the interest in Geoscience through Agenda 2030 topics, and could also indirectly contribute in improving multidisciplinary competences of the pupils using a practical and ludic application (Stacchiotti et al., 2019).

MATERIALS AND METHODS

S-City virtual Game has been tested both with K6-k8 students (totally, 69) and with their teachers (24). Most teachers (83.3%) were not familiar with virtual worlds, so an initial training to master how to move and interact in the world was necessary. During this phase, teachers acquired the basic skills to use their own avatar and interact with virtual objects. On the contrary, students didn't need a lot of explanations to move in the world because of their better familiarity with digital games and virtual worlds. Students and teachers were given a questionnaire in order to collect data for the experimentation (pre- and post-activity for students, only post-activity for teachers). The teachers' survey investigated if and how they have ever addressed their pupils to the Agenda 2030 topics. Furthermore, teachers expressed their level of satisfaction about the proposed activities and were asked to give some suggestions to improve them. The students' questionnaires investigated their familiarity with the Agenda 2030 topics and their involvement and satisfaction degree during the game. Both teachers' and students' questionnaires were composed of a series of statements to rank with a 5-point Likert scale and by open-answer questions to highlight strengths and weaknesses in the activities.

Game structure

Sustainability City Game first version was a cardboard one, to be played by 4 teams composed by 3-6 players. It is very similar to the Game of the Goose. Each team has an itinerary to follow in steps, to reach the heart of a sustainable city, starting from a conventional city. The itinerary includes individual and team challenges as disciplinary multiple-answer quizzes and mini-games. The virtual version of the game was developed in line with the cardboard one, but some adjustments have been made in order to adapt the activity for a virtual environment. It is planned to be played in teams (maximum 6) or individually. The avatars/players are the pawns of the game and move on the board game after rolling the dice (Figure. 3.A2b.2). Therefore, avatars wear a hat marked with the chosen SDG and take place on the corresponding box in the series that is in front of the board game. The team that plays first is that with the avatar located on the left side of this series and the round of gaming proceeds from the left to the right side.

At the beginning, players have to choose one of the 17 SDGs, in order to engage players in Agenda 2030 Goals. Each team is composed by 4-5 avatars that change during the game (in each game turn), in order to involve each component of the team in the activity as much as possible. Dice is shaped like an octahedron, in order to represent one of 16 SDGs on each face. The last SDG (17-partnership for the goals) is not considered but it is used as a slogan throughout the play-time to promote collaboration among pupils. The numbered boxes have different colors or images because they represent different tasks to pass.

After rolling the dice, the avatars move on the board and click on the landing box to start every task. Through an interactive panel and text chat, players can answer the questions or accomplish tasks. Some tests of the game are carried out using online educational apps, or sharing online interactive whiteboards.

Figure 3.A2b.2. *S-City virtual Game.*

If the playing team passes the task, it can move on its pawn/avatar of three boxes, otherwise it stays still in the same position. This golden rule has a symbolic meaning: citizens must improve their awareness and responsibility in their lifestyles in order to reach future Sustainability. In Tab. 3.A2b.1 the various tasks are listed explaining what they consist of and how they must be overcome.

In the cardboard game, players drew the cards and read questions: on the contrary, in the virtual version questions and tasks appear on interactive panels and teams answer via chat. The task "Challenge" consists of online games, while the "Prison" and the "Final challenge" task uses a shared whiteboard. When a team first reaches the final box, this team and all the others have to overcome the final challenge. The winner and the final ranking will be declared according to teachers and pupils' satisfaction degree regarding the results of this final challenge.

Table 3.A2b.1. *Description S-City Digital game tasks*

Boxes / Task to perform
Coloured boxes (disciplinary quizzes) Multiple-choice quizzes about natural resources consumption, aware lifestyles, circular economy, pollution, climate change and other Agenda 2030 topics. Quizzes are triggered by clicking on the landing box regarding to: - History (red boxes) - Science (green boxes) - Math (brown boxes) - Technology (gray boxes) - Citizenship (yellow boxes) - Geography (light blue boxes)

The Challenge All the players resolve online web app games directly from the virtual world (Word games, scrabbles, crosswords anagrams, speed games etc.)	
Guillotine Analyzing 4 key-words, all the players must guess the SDG corresponding, answering via an interactive menu.	
Guess the action Starting from a partial image representing a sustainable action, all the players have to guess that action, by clicking on an interactive menu.	
Prison Stop for one turn. The player can get out of prison through a particular test: to draw a sustainable action using a shared online whiteboard directly from the virtual world.	
Final Challenge - Arrival box Role Play on a shared whiteboard making a collage of digital texts, images and drawings. *Imagine an electoral campaign to support your adopted SDG*. Each player has to write the name, logo, slogan of their environmental movement and 3 key action-points of its campaign. Players have to share with the others their own program, explaining the reason for their choices.	

In each session of the game experimentation, the authors (with the help of the participating teachers) carefully observed and noted students' attitude and engagement, in order to highlight strengths and weaknesses of the game. These observations aimed to gather information for future game improvements. For example, a time counting and a timer for each task was determined to be necessary, to make sure that the play proceeds quickly. This fact allows pupils to really enjoy themselves during the activity, avoiding that they get bored, losing enthusiasm and motivation. Eventual explanations and deepings of the topics must develop at the end of the game. Finally, students were encouraged to participate in a debate to reflect critically on responsible lifestyles to become aware citizens.

RESULTS

The data, emerged from the evaluation of the questionnaires completed both by the teachers and the students, allowed to gain information on the validity and effectiveness of didactic activities proposed and the use of a game to convey them.

Experimentation with teachers

During the experimentation, teachers appreciated both the contents and the graphics of the virtual game. Focusing on teachers' questionnaire results, the data show that most teachers (70%) have already discussed the Agenda 2030 topics with their pupils at least on one occasion, although with only a general degree of explanation, during ordinary lessons. Only some of the teachers declared to have addressed these issues through an interdisciplinary approach. S-City Game virtual activities were satisfactory for all teachers and all of them declared that it is an effective educational tool to vehicle the key principles of Sustainable Development and good practices of everyday life.

From the analysis of teachers' satisfaction about the cardboard version of the game, its strengths were mainly interdisciplinary, pupils' engagement and improvement of social and critical thinking competencies. For the virtual version, in addition to these positive impressions, other strengths emerged, as shown in Tab. 3.A2b.2. In this table weaknesses of the activity are indicated and possible solutions for these weaknesses are proposed too.

Experimentation with students

The virtual game allowed students from schools in different Italian regions to address sustainability topics in a funny and enjoyable way. During the experimentations, students were pleasantly involved, showing a high level of emotional involvement and enthusiasm, thanks both to the interesting topics (linked to real life) and the didactic approach used. More in detail, the intersection of virtual-based activities and gaming as a didactic approach fascinated students who felt the "sense of presence" in the virtual world and a high involvement during all the activity. Regarding students' data satisfaction-questionnaire results, most pupils (more than 95%) declared, as expected, that the virtual version of S-City Game is an engaging activity to address Agenda 2030 topics.

Table 3.A3b.2. *Strengths and weaknesses of S-City virtual Game activity in teachers' opinion (answers in brackets).*

STRENGTHS	WEAKNESSES	POSSIBLE SOLUTIONS for weaknesses
Interactivity Engaging virtual scenario (33.3% agree, 66.7% strongly and completely agree) S-City virtual game can be played at a distance	Sometimes it is difficult to move across the different parts of the game (33.3%), slowing down playtime Sometimes rules are difficult to apply using the interactive panel (37.5%), causing the game to slow down (22.2%)	An extra-time devoted to the teachers' training before playing can be organized The interactive panels are managed by a programming language; therefore players have to respect their turn of the game and to press buttons only if it is necessary. An extra-time for teachers' training can be provided before playing with tutorial of the game

Furthermore, pupils appreciated both the graphical design and the virtual scenario of the game (85.7% pupils). More than 85% students declared it was easy to apply the rules of the game, interacting with the different panels. This percentage is higher than the teachers' one (62.5%), as expected given the students' greater familiarity with computer tools and the digital divide between teachers-students. Students' open answers highlight that interdisciplinarity, team working and the final challenge are the main strengths of the activity. Answering the question "*did you enjoy the task challenge, disciplinary quizzes, guillotine,* …?" pupils answered that all the game trials (70% answers range are agree/completely agree) were mostly fun and interesting. Analyzing the pre-activity and post-activity pupils' answers, some data about the learning effectiveness of the activity were collected. In Figure. 3.A2b.3 students' percentage of correct answers about sustainability topics definitions are reported, showing a much better performance after the activity.

Furthermore, pupils' awareness about the importance of responsible resources consumption and circular economy improved. For example, after the activity, most pupils recognize that soil and minerals are resources, and 54% of pupils think about the fact that even waste can represent a resource. The open-answer questions: "*how is your ideal sustainable city*?" and "*what would you do in your everyday life as a citizen of a sustainable city*?" allowed researchers to collect pupils' opinion. Table 3.A2b.3 reports the main topics emerged from the surveys.

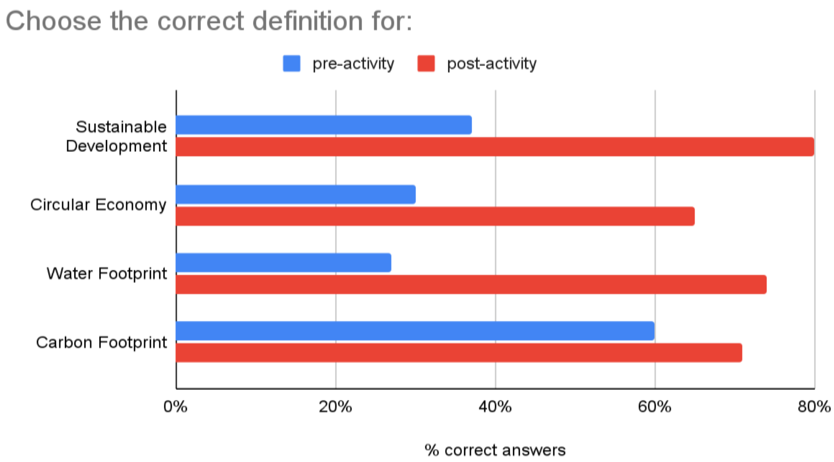

Figure. 3.A2b.3. *Percentage of pupils' correct answers about sustainability topics in pre- and post-activity questionnaire*

Table 3.A2b.3. *Students' thinking about the main features of a sustainable city and its citizens' lifestyles.*

My sustainable city	Citizens in a sustainable city and their lifestyles
-clean energy (39%)	-Recycling the waste (44%)
- green areas (35%)	-Reduce water waste (38%)
-social equity and dignity (26%)	-Moving by bike or walking (25%)
-responsible resources management (26%)	-Keep the common areas clean (24%)
-responsible waste management (22%)	-Reduce plastic utilization (22%)
-transports with lower carbon emissions (22%)	-Reduce domestic power consumption (16%)
-decrease pollution (19%)	-Stop food waste (13%)
-clean areas and roads (13%)	-Reuse objects (12%)
	-Be responsible in food consumption (7%)

DISCUSSION

Some points of interest were observed during the experimentation with teachers and pupils and others were evidenced thanks to the data evaluation.

The experimentation of the S-City Virtual Game activity allowed teachers to appreciate a digital game as a useful and motivational tool to vehicle Sustainable Development topics. They were pleasantly impressed by the interdisciplinarity of the game and the assortment of abilities and competencies required by players. Most teachers declared that, before the activity, had addressed sustainability with pupils only in a general way, without a well-structured didactic path based on interdisciplinarity.

Therefore, teachers appreciated S-City digital Game as a ready-to-use tool and expressed their wish to visit the Sustainability Hub island with their avatars and pupils' ones in order to replicate the game activity in their classrooms and in distance learning. Although some teachers stressed activity's weaknesses, the authors presented simple solutions to overcome them, as described in table 3.A2b.2.

The experimentation of the didactic activity with students approached them to Agenda 2030 Goals topics in an active way, although in the distance learning mode. Analyzing the pupils' satisfaction degree, they enjoyed the game, appreciating all the tasks in the same way. They declared to have a lot of fun and to have been pleasantly involved during all the game time. The team works well to overcome the trials without, in fact the team's components could easily talk and discuss the answers through digital resources such as microphone and chat. Regarding the pre- and post-activity questionnaires, a students' better performance was observed after the activity, especially in giving definitions about topics related to sustainability (e.g. water footprint and circular economy). Therefore, the S-City digital game has been evaluated as an effective tool to vehicle new concepts and improve new competencies, using distance learning. Despite the COVID-19 lockdown and school closing periods, , the researchers could actively involve students from different Italian regions, ensuring cooperative learning, problem solving and critical thinking. Digital tools such as virtual platforms, microphone and text chat, allowed pupils to discuss and interact with teachers and their peers, developing social skills in spite of the lockdown.

From pupils' opinion about their ideal sustainable city features and how they could act as aware citizens, some points of interest emerged. First of all, in addition to the common idea of green and clean cities, key-principles of a circular economy emerged. In fact, responsible waste management (also food waste), responsible use of resources such as water and energy and reuse of goods and objects are usual contents in pupils' opinion. Another important aspect is that social issues, like equity and dignified life for all (a core topic in Agenda 2030) are listed among the main features of a sustainable city and this result shows pupils' awareness about the multidimensional approach of sustainable development.

CONCLUSIONS

In education for sustainability, knowledge is important, but how students can apply that knowledge is more important. Attitudinal instruction and learning is more challenging than providing and gaining cognitive knowledge (Janakiraman, 2020). Simple pro-environmental changes in lifestyles always need a persuasive approach or pedagogical tool, in order to make pupils acquire performing behaviors in the real world. Traditional methods of instruction involving traditional lectures and tests will only ensure cognitive knowledge gain. On the contrary, an immersion in a game context that involves students in facing real issues, is more effective. The pleasure in intellectual engagement, the joy in learning and discussing good life practices and sustainable city's features is needed and useful, in pursuing understanding with passion and the exhilaration we see in fully rapt attention (de Castell, 2011). The game allowed a "learning by doing" approach providing hands-on and heads-on skill and knowledge improvement. The game asset made pupils protagonists of their own learning, since they were involved through several perceptual channels.

This game allows students to address Sustainable Development topics in a multidisciplinary manner, embracing a holistic approach. The tasks require problem-solving abilities, in order to deal with global actual issues, not only environmental, but also social such as the inequality in natural resources' distribution in the world. In Middle schools this activity represents a starting point for discussion during the school year, with strong effects on long-term retention of contents and knowledge. For example, the History teacher can address immigration issues connecting them with availability of resources and their exploitation, strengthening the concepts that emerge during the S-City Game activity. The activity was also effective in making pupils aware of the human role on the planet, recognizing that Earth's resources are limited and not equally distributed among different countries. The game offers also the possibility to reflect about simple but effective actions to take in everyday life to increase sustainable awareness. Students are protagonists of the game and of their own learning. Therefore, they can contribute to the dissemination of Sustainability issues among peers and families, becoming active change-makers and promoters of a new environmentally-friendly culture.

Furthermore, S-City game has proven to be a successful educational tool for growing interest in Geoscience topics that concern most Agenda 2030 goals. The choice of Geoscience-related topics allowed students to acquire new knowledge and competences about Sustainability, with its many interconnections with Geosciences. Despite the distance learning, adopted by Italian schools during COVID-19 pandemic, the virtual game has been an effective tool to realize didactic experiential activities allowing students to work in a team, discuss each other through chats, and learn in an active way.

ACKNOWLEDGEMENTS

Special thanks are due to the teachers who collaborated by participating in the experiment with their students, giving suggestions and comments useful to improving the game.

3. A3. Powerland - FrameVR

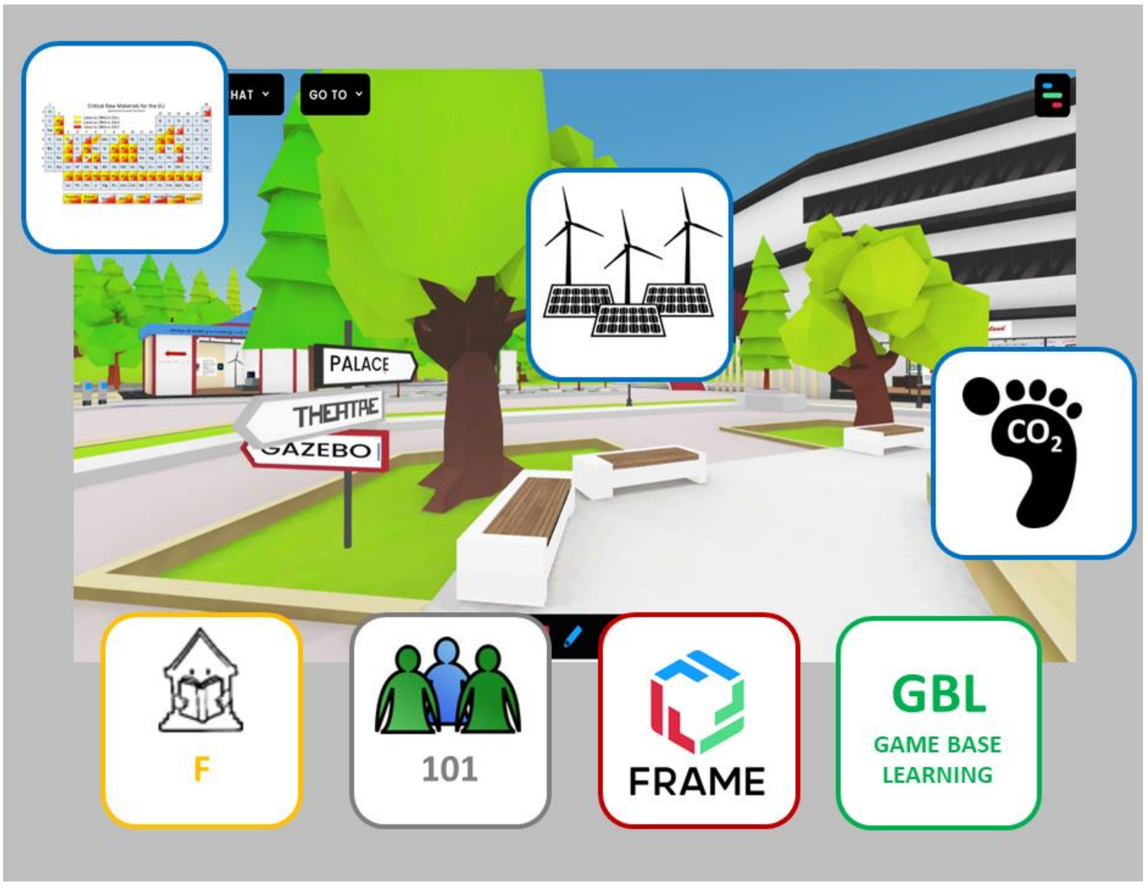

Figure 3.A3.1. *Summary of the project*

3.1. AIMS OF THE PROJECT

Material as lithium, cobalt, indium, silicon and rare earth elements are defined Energy-Critical Elements as they are used in renewable energy and energy storage devices. The energy transition towards renewable energy (to decrease greenhouse emissions) and the digital technologies raised the importance of these minerals (Figure 3.A3.2) defined as "critical" related to the long availability term, the supply situation, the recyclability and environmental conditions that regulate their extraction (Viebahn et al., 2015). According to Viebahn, "the large-scale deployment of renewable energies is expected to cause increase demand of critical mineral resources", highlighting important aspects related to their carbon footprint, technical process problems (e.g. separation of rare earth elements) and social and geopolitical concerns. In fact, the production of renewable energy requires more minerals than their fossil fuel-based counterparts (IEA, 2021). For example, in a typical electric car there are six times the mineral quantity of a conventional vehicle, and an onshore wind power plant requires nine times the mineral resources of a natural gas plant (Kirsten et al., 2020).

School should have the responsibility of raising students' awareness on these issues, pointing on lights and shadows in the use of renewable energy and electric mobility. Generally, these issues are not part of the science curriculum of Italian low secondary schools, K6-K8 grade (MIUR, 2012).

This activity presented here was set up having in mind the following take-home messages for students, properly simplified for their age range:

- Few countries have the monopoly of these elements (IEA, 2021), so they could limit export to satisfy internal request. This fact can lead to geopolitics issues.
- The separation of Rare Earth Elements (REE), due to the similar chemical and physical properties, cause a high environmental impact (Koltun and Tharumarajah, 2014).
- Many deposits of minerals are in developing countries, such as Cobalt in Democratic Republic of Congo, where mining violates human rights protections and workers' health and safety (Sovacool, 2019)

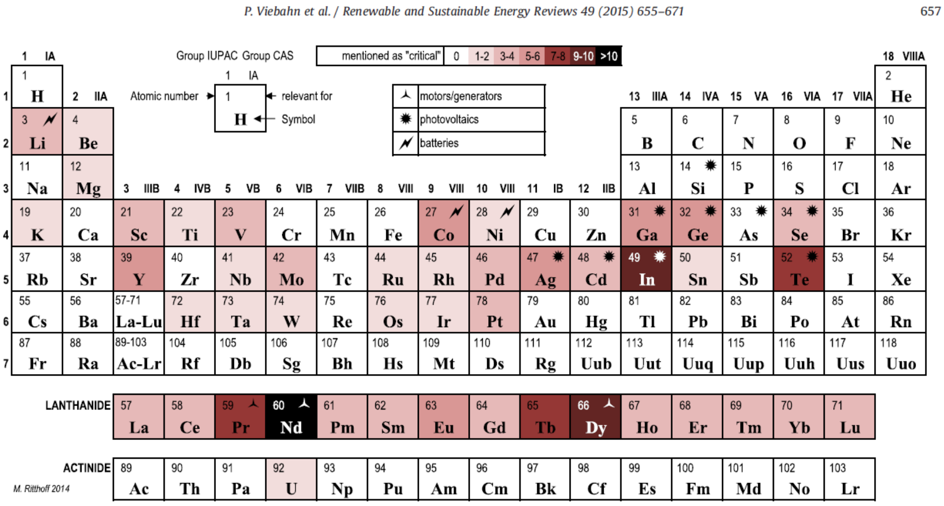

Fig. 1. "Criticality" and usage of elements according to an evaluation of 12 studies.

***Fig 3.A3.2.** "Criticality and usage of elements" according to an evaluation of 12 studies (based on the number of times they have been called "critical". From P. Vielbahn et al. Renewable and Sustainable Energy Reviews 49 (2015) 655-671*

3.2. TOPICS ADDRESSED

The European Critical Raw Materials Act is a policy initiative by the European Commission to secure sustainable supplies of critical raw materials and to support the EU's green and digital transition. It includes measures to strengthen domestic supply chains, reinforce international engagement and promote education, research and innovation in the sector. The European Federation of Geologists (EFG) support the European Commission and EU Parliament about these topics. EFG (2022) stressed the importance of geoscientific education and research to "ensure a talent pipeline along the critical mineral supply chain" and "develop innovation projects that optimize the recycling and/or substitution of critical minerals".

To date there are few cases of educational programs to increase the awareness of young students about the importance of critical raw material. Among them, RM@Schools, an EU Consortium by EIT Raw Materials, has the aim to introduce students in experiments and science dissemination and create educational toolkits based also on gamification (Murphy & Pacher, 2021). BetterGeoEdu is one of the toolkits, which use a modification of Minecraft where students can experiment "direct applications of minerals and rocks in the manufacturing of building and construction materials" (Herrera et al, 2021). Cho and Park (2023) listed a series of environmental education activities experienced using virtual and augmented reality. These activities are mainly focused on pollution, climate change, ecosystems, but there are no works specifically related to raw critical materials.

Considering the scarce literature, we decided to address the importance of particular raw materials. The educational path in this activity was developed to address the following topics:

- Fossil fuel and climate change
- Production of renewable energy
- Carbon footprint of energy production
- Critical minerals for technology and energy transition (in particular Lithium, Cobalt, Tantalum, Rare Earth Elements, Neodymium, Niobium) and Waste of Electric and Electronic Equipment (WEEE)
- Electricity consumption

All content was developed using as data source institutional agency reports and research articles, simplifying concept for the target population.

3.3. DESCRIPTION OF THE LEARNING SCENARIO

The didactic activity was carried out in a web immersive platform (Gómez et al., 2021) called Frame (framevr.io), suitable to easily create educational environments, where students, accessing as avatars, can explore contents and collaborate to solve games, challenges and accomplish missions. The free plan of FrameVR state that up to 15 avatars can stay in a world at the same time so, to host an entire cohort of students, three identical virtual worlds were created, to host 2 teams of 3-4 students each. A library template from the site framevr.io was used, and contents (images, multimedia presentations, links to external online games, 3D objects) were added. In every world all content were doubled, so two teams could explore different parts of the educational scenario without interference. The educational path was divided into 5 sections (three sections in the "Palace" and two sections on the "Gazebo" area, reflecting the topics listed in paragraph 3.2. Furthermore, in another area, pupils could symbolically plant the trees necessary to offset their carbon footprint calculated in the previous week in the activity in the virtual world. In Figure 3.A3.3 the thematic sections are shown. Powerland FrameVR can be reached at the site framevr.io/energy.

One of the main reasons to experiment with a web-based virtual worlds come from the need to work also with low-end personal computer such as Chromebooks, easily found in schools especially during the Covid-19 pandemic, when it was necessary to buy a high number of devices for students at home. In fact, Apps such as the Firestorm viewers for Opensimulator-based virtual worlds can't run on Chromebooks. This learning scenario is suitable therefore to be explored also using a virtual reality headset.

3.4. STUDY POPULATION AND SETTING

The project involved 101 K8 students (age 14-years-old) of the school F (46.5 % males e 53.5 % females), accessing the world from the computer laboratory, during the normal school time, under the supervision of 6 science teachers. I was connected in remote, in sharing screen mode and accessing with an avatar in each world to give support, if necessary. A two-hours meeting was used for each class.

The experimentation involved also 21 students of the school N (age 14-years-old), 52.4% males and 47.6 females). The results obtained for this group of students will be reported in the section A4, as comparison with a group of students of the same school using the platform Opensimulator.

Figure 3.A3.3. *On the top, left to right: the Palace with the first three sections of the educational path; the atrium of the Palace where students get the "mission sheet". At the bottom, from left to right: The "CO_2 balancing area"; the "Critical mineral for energy transition and technology" area with some learning objects such as links to external online games, multimedia presentations, info panels and 3D objects.*

3.5. PHASES OF THE PROJECT

The experimentation was preceded by an online plenary meeting where it was explained how to access the platform and use its basic function. The aim of the project and the tasks to accomplish the activity were also displayed. In the preliminary meeting a custom-made carbon footprint calculator (developed simplifying the one reported at www.carbonindependent.org) was shown to the students. They were asked to calculate their domestic carbon footprint, searching for data at home in the following week.

At the beginning of each meeting students were asked to complete a pre-activity survey (see section "Results" and Annex 3.A3.1). Then, they got acquainted with the platform (accessible via a link in the browser web) and customized their avatar.

In the atrium of the Palace students' teams, via a link in the world, accessed an online form (called the Mission Sheet) where a series of 30 questions have to be answered, searching information in the multimedia presentations placed in the various sections of the scenario and solving together online games (crossword puzzle, matching pairs, group assignment, simple order and so on). Online games were developed with a specific app, Learningapps (https://learningapps.org). In Annex 3.A3.2 there are the links to the online games. In the section "Electric consumption", students were requested to calculate the electric consumption of a stand-by led in 1 years and report the value in the relative virtual whiteboard. Mission aimed to give gamification characteristics to the activity and engage students.

After 2 hours, at the end of the activity, the "Mission Sheet" was delivered to me. Then, the same day during the school time, they complete a post-activity questionnaire, which includes a knowledge test and a satisfaction questionnaire. A satisfaction questionnaire was administered also to the teachers involved, aimed to collect information about the quality of the activity and the behavior of the students.

3.6. RESULTS

3.6.1. Reliability

In this section the results of both the knowledge tests and the satisfaction questionnaire of students and teachers are reported. Values of reliability (Cronbach alpha) are displayed when necessary. Reliability (Chronbach alpha) was calculated on the first group of students who perform the test, the group 1. Its value is related to 25 questions and it is equal to 0.76, testifying the high reliability of the test.

3.6.2. Mission sheet

The Mission Sheet results show a good value of correct answers (mean 73.5%). In Table 3.A3.1 results are summarized for each class as a mean of the six teams.

Table 3.A3.1. *Summary of the "Mission sheet" results*

CLASS	1	2	3	4	5	6	7	Mean
Mean "Mission sheet" score %	86.1	70.0	63.3	Not sent by the teams for technical reasons	63.3	66.7	91.7	73.5
Std. Dev.	11.2	4.2	18.4		15.3	21.4	11.3	12.3

The student teams of the class labeled as "4" didn't sent the online form due to connection issue at the end of the meeting. Both the online games and the mission sheet worked as training to answer to the post-activity knowledge test (although the students didn't know), which had similar questions.

3.6.3. Knowledge test

The analysis of pre-activity and post-activity surveys, based on 25-points score reveal a significative increase (P value <.001) of the mean total score (from 58.5% to 71.8%) (Table 3.A3.2). The questions concerned general question about fossil fuels, renewable energy and critical mineral related to energy (Annex 3.A3.1 and 3.A3.3). Twelve additional questions were administered only in the post-activity questionnaire, related to specific question of the critical materials involved in the energy transition, such as their chemical and physical propertied, their environmental impact and their geographic distribution.

The mean score of this additional test was just a little lower to the former (mean 69.3%, standard deviation 15.1) but not statistically significant (P value >0.05). 55% of the students reported the value of their carbon footprint in the pre-activity questionnaire. In addition, there is no difference between male and female (P value = .886 for the pre-activity and P value = .978 for the post-activity).

In Table 3.A3.3 the results for each class are reported.

From data in Table 3.A3a3. It emerges that:

1) In the pre activity test all classes are statistically equivalent (P value = .432)
2) In the post-activity test the class labeled as 5 obtained results significant different than the others (P value = .017 including class n. 5 and P value =.597 excluding it).

In addition, no significant differences were found between male and female results in all tests (P value higher than 0.8).

In Table 3.A3.4, the total 37 questions of the post activity test have been grouped in categories with the relative mean score.

Table 3.A3.2. *Results of the knowledge test (global students)*

	Pre Activity (25 questions)	Post activity (25 questions)	12 additional questions	Total (37 questions)
Mean Test score %	58.5	71.8	69.3	71.0
Std. Dev.	12.6	13.6	15.1	12.0
Mean std. error	1.3	1.4	1.5	1.2
Cronbach alpha		.62		0.67
Related-Samples Wilcoxon Signed Rank Test (P value)	<.001 (*)			
		0.078 (**)		

(*) Comparison between pre and post activity

(**) Comparison between the 25-question knowledge test and the total 37-questions (including the 12 additional questions)

Table 3.A3.3. *Results of the knowledge test (by class)*

Test	**Class**	**N. students**	**Mean test score (%)**	**Std Dev**	**Std Error**	**Independent-Samples Kruskal-Wallis Test (P value)**	
Pre activity test (25 questions)	1	12	58.0	15.1	4.4	.432 (class 5 included)	.736 (class 5 excluded)
	2	12	58.3	16.2	4.7		
	3	14	63.1	9.4	2.5		
	4	8	58.5	12.3	4.3		
	6	15	57.1	11.2	2.9		
	7	22	60.9	12.2	2.6		
	5	18	53.8	12.2	2.9		
	Total	**101**	**58.5**	**12.6**	**1.3**		
Post activity test (25 questions)	1	14	75.4	16.7	4.5	.017 (class 5 included)	.597 (class 5 excluded)
	2	10	68.4	12.0	3.8		
	3	14	71.7	11.5	3.1		
	4	8	75.0	13.5	4.8		
	6	15	71.7	13.7	3.5		
	7	22	78.0	11.6	2.5		
	5	18	62.2	11.3	2.7		
	Total	**101**	**71.8**	**13.6**	**1.4**		

3.6.4. Students' satisfaction survey and digital skills

A set of statements rated by a 5-point Likert scale were delivered to students to collect information about their perception of the quality of the scenario, of the learning experience and the ease of use of the platform (Annex 3S.3). Students appreciated the activity (all median = 4), feeling confident with the platform and the contents proposed. More details on the satisfaction survey are reported in section 3.S.

Table 3.A3.4. *Knowledge test score of students (by topics)*

Category	N. questions	Mean score (%)
Distribution and geopolitics of critical minerals	4	66.3
Critical minerals properties and production	10	66.3
Fossil fuel and climate change	9	73.6
Renewable energy	8	77.1
Energy production and carbon footprint	4	67.1
Agenda 2030	2	75.7

In addition, two open ended questions were added, about suggestions to improve Powerland FrameVR (Figure 3.A3.4), and advantages and disadvantages of virtual words in distance learning (discussed in section 3.S). These questions were optional, so a high percentage of students didn't' answers.

3.6.5. Monitoring and teachers' satisfaction survey

The response of the 6 teachers who supported the students during the activity in the computer lab evidenced that gamification is a good approach to engage students (50% of teachers) but time to accomplish the mission must be longer (50% of teachers) by adding more meetings with less topics at a time or visiting the scenario along all the school year. Time was the only point of weakness reported by teachers. In Table 3.A3.5 a list of statements rated by a 5-point Likert scale is reported.

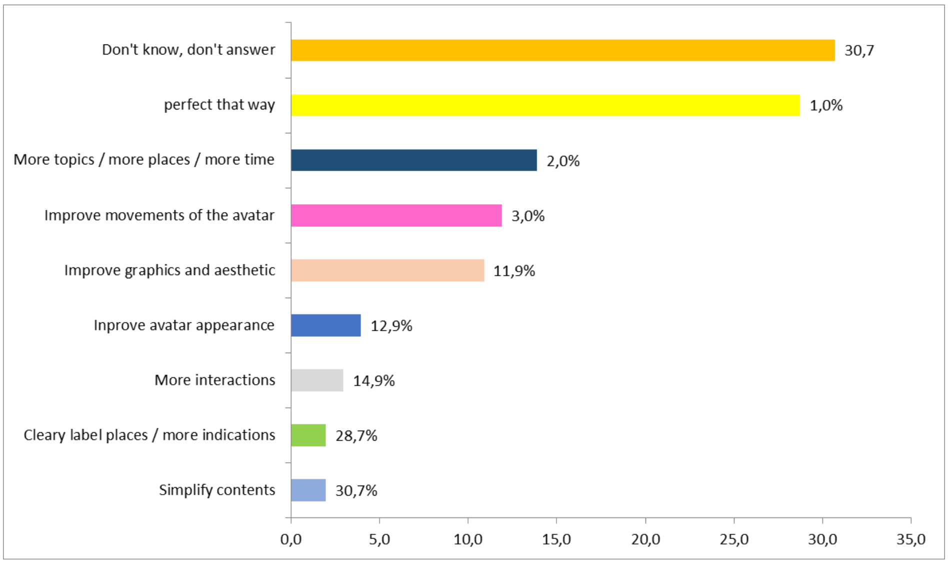

Figure 3.A3.4. *Open-ended questions – Students' suggestions to improve Powerland*

3.7. DISCUSSION

From the analysis of the mission sheet, the knowledge test and the satisfaction survey, it emerges the high engagement of students and the appropriateness of the activity, combining gamification, virtual worlds and team collaboration. Students got good results in all the topics proposed, although these topics are not part of the Italian curriculum of science and technology for the lower secondary school (MIUR, 2012). Students learned about the main features of critical minerals for energy transition and energy storage, but also the environmental impact of their extraction, as proposed by BETTERGEOEDU in the Minecraft platform for various construction materials.

In a systematic review, Pellas (2020) highlighted the potential of gamification in virtual worlds and Lee and Hwang (2022) stressed the importance of social VR platform as FrameVR to "ensure multimodal learning opportunities based on a real human interaction". Although this experimentation was not intended to test these interactions (students participate in person from the computer laboratory) it gave findings about the influence of an engaging environment on learning.

As described in chapter 1, web based virtual worlds have a great potential to be used in education. They are easily accessible through a web link, do not require high-end Personal computer and the user interface is simple and friendly so require minimal training. Respect to the Opensimulator platform, until now, do not have features to trigger events by the user, such as starting an animation or interact with panel and button (Mourdi et al., 2018). In this experimentation this issue has been overcomes by inserting links to interactive online games.

Table 3.A3.5. *Teachers' satisfaction questionnaire and monitoring*

Please rate your level of agreement with each of the following statements related to Powerland FrameVR	Mean Likert scale	Mdn
QUALITY OF THE EDUCATIONAL SCENARIO		
The educational pathway is consistent with the sustainability topics	3.7	3.5
The learning scenario is engaging	4.2	4
Learning path to follow is not clearly highlighted (RS)	5.0	5
Information was clear and explanatory	3.8	4
The content offered is appropriate to the age of the pupils	3.5	3.5
Online games are suitable for learning	4.2	4
The activity is suitable to convey content relating to sustainability	4.0	4
The activity allows to improve of active citizenship skills	3.8	4
The activity allows to improve some digital skills	4.0	4
The activity is suitable for integrated digital teaching	4.0	4
This approach (virtual/gamification) can be applied to STEM topics	4.0	4
ORGANIZATION OF THE ACTIVITY		
Carrying out the activity as a "mission" was not effective (RS)	3.8	5
The number of activities for pupils is too high (RS)	3.7	4
The time allotted for the activity was sufficient to complete it	3.3	3.5
Some technical difficulties affected the activity (RS)	4.0	4
It is useful to precede the activity with an introductory seminar	3.8	4
During the experimentation students seem to be involved and participatory	4.2	3.5
STUDENTS' MONITORING		
The attention of the pupils during the activity was inconsistent (RS)	3.8	4
The team collaboration has been fruitful	3.3	3.5
Students felt comfortable in the virtual environment (movement, interaction with links, …)	4.0	4

Likert scale: 1 Strongly disagree…. 5: Strongly agree. Statements labeled with (RS) are reverse scored.

Although less flexible than Opensimulator, FrameVR has the advantage to be easier to use, at zero costs (by the trial plan) and require less time both to teacher to implement the activity and students to master all the features. A comparison between FrameVR and Opensim in the perception of students is reported in section 3.S. In the next sections is described an identical educational path implemented in Opensimulator, and the two platforms, Opensimulator and FrameVR, are compared in terms of ease of use and test results.

In Table 3.A3.6 the mean Likert scale grade for each teacher is reported, based on all the 20 questions of the teacher satisfaction survey.

Table 3.A3.6. *Satisfaction questionnaire results (by teacher)*

Teacher	Mean Likert scale (20 questions)	STD
1	3.8	0.6
2	3.8	1.0
3	4.4	0.8
4	4.0	0.8
5	3.9	0.9
6	3.4	0.9

3.8. CONCLUSIONS

The activity allowed to approach complex topics related to renewable energy production and the use of critical minerals, which are not part of the curriculum of science and technology for this age range (11-14 years). Notwithstanding this, the activity was successful in introducing the students to these themes, using an engaging approach. The main findings of this experimentation using Frame VR can be summarize as follow:

- It was needed relatively short time for teachers to implement content in a web-based virtual world
- It was needed short time for student to master the world's tools
- Activity do not need high PC requirements
- No costs to implement the activity
- Gamification features improve learning (good test scores)

All these results are promising for an implementation at large scale of this activity, using also headset devices.

A video showing the activity can be seen at:
https://www.virtualscience.it/video/powerland-framevr.mp4

3. A4. Powerland - Opensimulator

Figure 3.A4.1. *Summary of the project*

3.1. AIMS OF THE PROJECT

This part is partially reported for completeness from Section 3.A3.

Material as lithium, cobalt, indium, silicon and rare earth elements are defined Energy-Critical Elements as they are used in renewable energy and energy storage devices. The energy transition towards renewable energy (to decrease greenhouse emissions) and the digital technologies raised the importance of these minerals defined as "critical" related to the long availability term, the supply situation, the recyclability and environmental conditions that regulate their extraction (Viebahn, 2015).

School should have the responsibility of raising students' awareness on these issues, pointing on lights and shadows in the use of renewable energy and electric mobility. Students should take into account the high environmental impact of critical minerals, the geopolitical issues caused by the fact that few countries have the monopoly of these elements (IEA, 2021), and their mining in developing countries, such as Cobalt in Democratic Republic of Congo, often violates human rights protections and workers' health and safety (Sovacool, 2019).

3.2. TOPIC ADDRESSED

This part is partially reported for completeness from Section 3.A3.

The educational path in this activity was developed to address the following topics:

- Fossil fuel and climate change
- Production of renewable energy
- Carbon footprint of energy production
- Critical minerals for technology and energy transition (in particular Lithium, Cobalt, Tantalum, Rare Earth Elements, Neodymium, Niobium) and Waste of Electric and Electronic Equipment (WEEE)
- Electricity consumption

All content was developed using as data source institutional agency reports and research articles, simplifying concept for the target population.

3.3. DESCRIPTION OF THE LEARNING SCENARIO

The didactic activity was carried at Techland, in an island called Powerland which hosts a series of renewable and non-renewable power plants and an escape room about electric consumptions (this last has not been included in this PhD research). In that island, the same educational path described in section 3.A3 was implemented, using the same multimedia presentations and the same links to online game. In addition, a series of 3D animated objects were added, such as a combustion reaction, a carbon dioxide detector and so on. In Figure 3.A4.2, the thematic sections are shown.

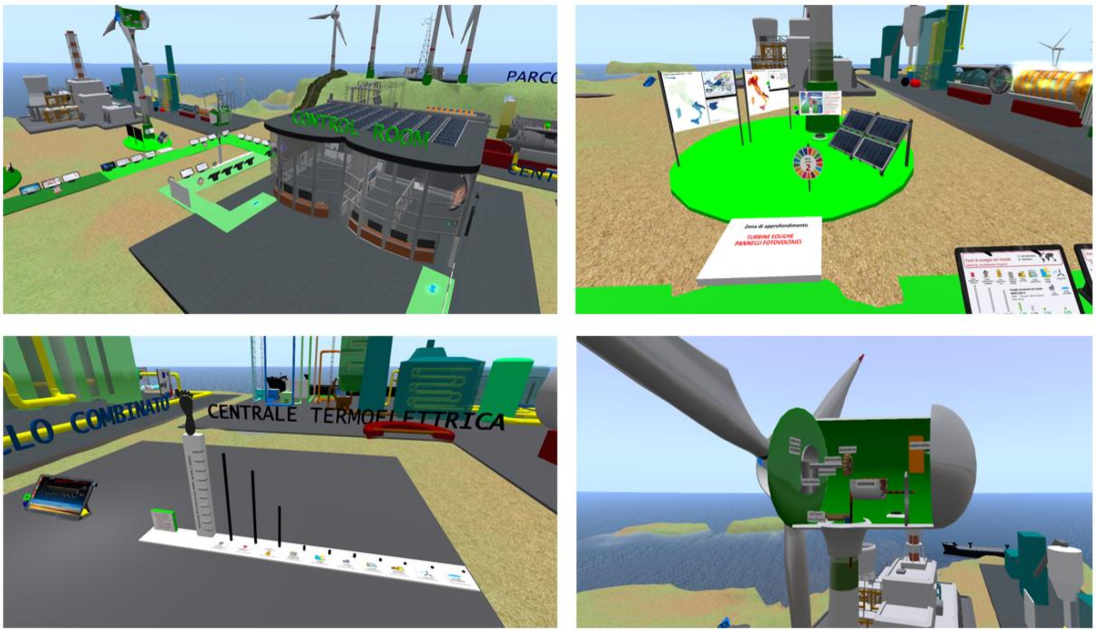

Figure 3.A4.2*. On the top, left to right: the educational path with the first three sections (green street) and the "Control Room" displaying critical minerals topics; "Energy production area" with some learning objects such as a link to an external online game, multimedia presentations, info panels and 3D objects. At bottom, from left to right: an interactive graph of Carbon Footprint of energy production; an animating interior of a wind turbine.*

3.4. STUDY POPULATION AND SETTING

The project involved 16 K8 students of the school N (50.0 % males e 50.0 % females), accessing the world from the classroom, during the normal school time, under the supervision of one science teacher. I was connected in remote, in sharing screen mode and accessing with an avatar in Powerland to give support, if necessary. The activity was carried out in a two-hours meeting.

3.5. PHASES OF THE PROJECT

The cohort of students involved in the activity had just finished a 20-hours project at another Techland island, so a training meeting for using the Firestorm viewer was not necessary. Just the aim of the project and the tasks to accomplish the activity were explained.

The activity followed the same steps as described in section A3 "Phases of the project", using the same "Mission sheet" and the same pre- and post- activity questionnaires.

3.6. RESULTS

Results were collected both by evaluating the "Mission sheet" and the pre- and post-activity questionnaires. In this section results of 21 K8 students of the school N using FrameVR and a summary of the activity A3 results are also included for comparison.

Reliability, in terms of Cronbach alpha value, is related to 25 questions and it is equal to .76, testifying the high reliability of the test.

3.6.1. Mission sheet

The Mission Sheet results show a good proportion of correct answers (mean 73.9%), not significantly different from those obtained with the platform FrameVR. In Table 3.A4.1 results from both schools are compared. The column N Opensim refers to the activity A4 described in this section; the columns N FrameVR and F FrameVR have been reported from the activity A3 described in section 3.A3 for comparison.

Table 3.A4.1. *Summary of the "Mission sheet" results*

SCHOOL / PLATFORM	N Opensim	N FrameVR	F FrameVR	Independent-Samples Kruskal-Wallis Test (P value)
Mean "Mission sheet" score %	73.9	75.0	73.5	.952
Std. Dev.	16.3	10.3	12.3	
N. TEAMS	6	6	36	

3.6.2. Knowledge test

Questionnaires of pre- and post-activity are the same of the activity A3 and they are reported in Annex 3.A3.1 and 3.A3.3. As activity A3, a group of 25 questions was used to compare pre-and post-activity results. Students increased their global mean test score. In addition, a group of 12 questions was reported only in the post-activity test. The results from the 12-additional questions were lower respect to the 25-group of questions (mean 65.1%, standard deviation 18.3) but not statistically significant (P value higher than 0.05) (Table 3.A4.2). Similar consideration can be applied to the N class which experimented FrameVR (Table 3.A4.3).

In Figure 3.A4.3, it emerges that results from schools F and N are statistically equivalent.

Table 3.A4.2. *Results of the knowledge test– School N Platform Opensimulator*

	N	Pre Activity (25 questions)	Post activity (25 questions)	12 additional questions	Total (37 questions)
Mean Test score %	16	59.5	71.3	65.1	68.6
Std. Dev.		11.6	9.6	18.3	10.8
Mean std. error		2.9	2.4	4.6	2.7
Related-Samples Wilcoxon Signed Rank Test (P value)		.002		> .179	

Table 3.A4.3. *Results of the knowledge test– School N Platform FrameVR*

	N	Pre Activity (25 questions)	Post activity (25 questions)	12 additional questions	Total (37 questions)
Mean Test score %	21	62.9	77.5	74.6	76.6
Std. Dev.		11.0	13.9	22.3	15.5
Mean std. error		2.4	3.0	4.9	3.4
Related-Samples Wilcoxon Signed Rank Test (P value)		<.001		.953	

3.6.3. Comparison of the features of FrameVR and Opensimulator

The 21 N students who participate to the FrameVR experimentation were involved also in the activity A5 (Opensimulator). Therefore, in two additional 2-hour meetings, they also experimented in depth all the tools of the FrameVR platform. For each feature students were asked to express their preferred platform (Opensim, FrameVR, Equivalent, Don't' Know) regarding all the features listed in Figure 3.A4.4.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	
1	The distribution of POST_25 is the same across categories of SCHOOL_PLATFORM.	Independent-Samples Kruskal-Wallis Test	,215	

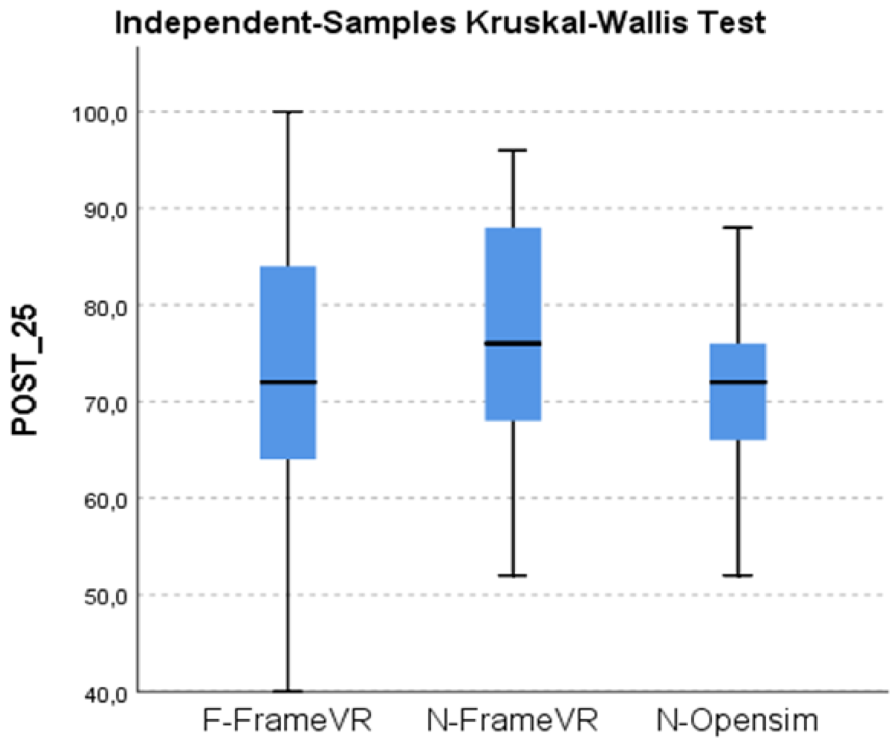

Figure. 3.A4.3. *Comparison between results obtained by the different schools using different platforms. The P value show that results are statistically equivalent.*

Figure 3.A4.4 show that web–based virtual world work better as meeting environment while Opensim is preferred as building environment, especially regarding the interactivity of the objects. Students judged the avatars more aesthetical and customizable. Nevertheless, they perceived FrameVR as the easiest to use.

3.7. DISCUSSION

The equivalence between the two types of platforms Opensimulator and Frame VR in terms of knowledge tests lays the foundation for more large-scale dissemination of this (and possibly others) activity about critical minerals-related topics on virtual worlds. As explained in Section A3, the higher ease of use and the shorter time to deploy activities in FrameVR compared to Opensim, underpin the promising development of web-based virtual worlds for geoscience education. Opensimulator has on its side higher interactivity with 3D objects, which in some ways act as "mindtools" while also explaining abstract concepts through appropriate animations (Jonassen & Carr, 2000). In the relatively short time of experimentation (2h) probably the presence of interactive 3D objects in the Opensimulator scenario did not affect the test results taking into account that students considered as a priority to finish the "Mission" rather than to deepen the concepts with 3D objects. Further research will be needed to explore this aspect.

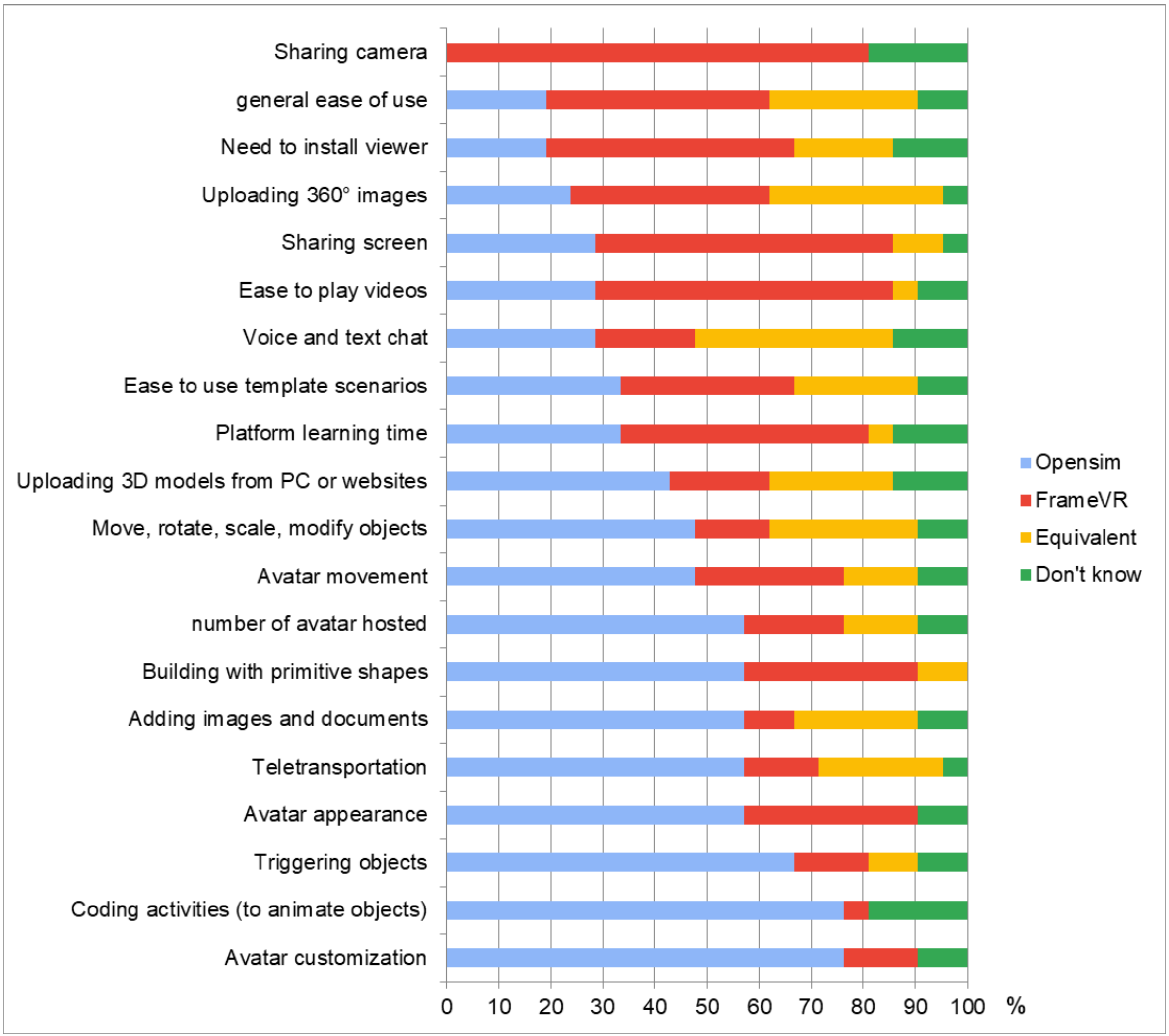

Fig. 3.A4.4. *Features of Opensimulator and FrameVR*

3.8. CONCLUSIONS

Web-based virtual world are promising tools to teach students sustainability topics in virtual worlds. Students are easily engaged even in difficult topics, with good results in terms of knowledge and acquisition of new ICT skills. Students who test both platforms shown to be comfortable in using both.

A video showing the activity can be seen at:

https://www.virtualscience.it/video/powerland-opensim.mp4

3. A5. Ecocity

Figure 3.A5.1. *Summary of the project*

3.1. AIMS OF THE PROJECT

In a review of recent environmental education (EE) research, Jorgenson et al. (2019) stated how education about energy and climate change, until now, focused primarily on energy saving as an individual behavior, not on energy transition towards renewable energies, stressing the need to give more importance to collective actions (e.g. governance, activism) and the role of technology in the energy transition.

For young students it is important to start thinking what they can do as “individuals” in their everyday life and after contextualizing their behavior as citizens of sustainable cities (collective actions), with a focal point also to resources and technologies needed for the ecological transition. Therefore, a didactic activity was planned and built up with the aim to transmit students the following “take home messages”:

- There is a need to lower individuals’ Carbon Footprint, starting from the daily routines
- Science and technology already have important solutions to reduce energy consumption and carbon footprint
- The energy transition involves critical minerals which have a great environmental impact, since their extraction, exploitation and use is energy-intensive

- Some critical minerals, as Lithium, Cobalt and Tantalum are also used in the students' electronic device, so the production of smartphones is energy-intensive and affects the environment

To foster the acquisition of these take-home messages, the general aim of this project for students is to be able to imagine more sustainable lifestyles. To achieve this objective, students are introduced to the concept of the environmental impact of green energy and common technology, by dealing with the calculation of the carbon footprint and imagining ways to reduce it.

3.2. TOPICS ADDRESSED

To reduce the greenhouse emissions, the main responsible of global warming (IEA, 2021), the Intergovernmental Panel on Climate Change (IPCC) highlights the urgent need to reduce the use of fossil fuels, radically changing our energy system (IPCC, 2014, 2018). This is the reason why in the last decade we assisted to a considerably rise of renewable energies productions, although after the pandemic, the need to recover world economy led back to an increasing use of coal and other fossil fuels. This contributed strongly to making the 2021 the second annual record of greenhouse gas emissions of all history of monitoring. Therefore, it is necessary to scaling up solar and wind rapidly, quadrupling the power installed (GW) by 2030 (IEA, 2021).

In 2021, the world primary energy consumption was estimated in 595.15 EJ (165320 TWh) and has approximately tripled over the past fifty years, accounting 82% from fossil fuels. The remaining sources include nuclear power, biofuels, hydropower, solar, wind and geothermal energy (BP, 2022). Therefore, at the present, the energy sector is responsible of three quarter of the total greenhouse emissions, expected to increase by about two billion over the next twenty years, estimating that by 2040 electricity generation probably will increase of nearly 52% (IEA, 2022). This value must be taken carefully into account, due to the long-term uncertainty such as geopolitical concerns or technological advances. At the time of writing this paper, in fact, the Russia-Ukraine war is on, with skyrocketing prices and heavy repercussion on gas furniture to EU countries, since Russia accounted for 20-40% of the EU's oil, gas, and coal consumption in 2021 (BP, 2022).

"Currently, cities are responsible for more than 70% of global energy consumption and associated greenhouse gas emissions" (UN-HABITAT, 2022) and "consume over 75% of the planet's material resources, although cities only cover 2% of the world's land surface" (IRP, 2018). According to the Global Status Report for Buildings and Construction (2022), the residential sector accounted for 34% of global energy demand with consequent 37% of energy-related emissions in 2021. Therefore, cities are "the problem" but can, and have the responsibility to be part of "the solution". In cities all technical, logistical and political measures to lower energy consumes and greenhouse emissions could have a big impact on CO_2 emissions (UN-Habitat, 2021).

The evaluation of a process in terms of climate change cannot ignore the calculation of the Carbon Footprint (CF) (Pandey et al., 2011), that is becoming mainstream to calculate the greenhouse emissions of industrial processes and services. Over the time, several definitions of carbon footprint were used, mostly referring to the emission of CO_2 and other greenhouse gases expressed as CO_2-equivalent. Here is reported the definition according to Wiedmann and Minx, (2008): "The carbon footprint is a measure of the exclusive total amount of CO_2 emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product". As an example, regarding electricity production, in EU there was a gradual reduction of the CO_2

emission per KWh at the final consume (from 641 gCO_{2eq}/kWh in 1990 to 334 gCO_{2eq}/kWh in 2019), although with a great variability among States. In fact, the value for Italy is 356 gCO_{2eq}/kWh (Scarlat et al., 2022). Regarding the greenhouse emissions, the World Energy Outlook (IEA, 2021) also stated that 55% of the greenhouse emissions will be strictly related to the citizen choices (as retrofitting an old building, installing a heat pump or switch to an electric car).

To plan this activity, the choice of topics to be addressed was carried out thanks to the students' interest emerged from the pre-activity survey (See "RESULTS" section, paragraph 3.6.1.) where the students chose from a list the main factors that increase the sustainability of a city and, in an open-ended question, highlighted the main characteristics of a sustainable city, in their opinion. Based on students' answers (paragraph 3.6.1) the topics to be developed in the project were decided. Here a brief list: sustainability, renewable sources, electric consumption, carbon footprint (CF), systems and solutions for reducing the carbon footprint.

3.3. DESCRIPTION OF THE LEARNING SCENARIO

Ecocity is one of the islands of the sustainability section of Techland, focused on urban sustainability. It was planned as an infrastructure, a sort of template where students can design and develop new sustainability characteristic and features, personalizing the city building specific elements (for example photovoltaic panels, horizontal wind turbines, solar charging electric power units and so on). It is a multipurpose environment intended to be experimented by different cohort of students in different projects, all related to urban sustainability. It includes the typical service and organization of a city, with a government palace, a mobility hub with the train station, bus station and car and bike share, urban gardens, shops and buildings. To accomplish the experimentation, the authors decide to use an active learning approach, based on Inquiry based learning (IBL) and problem-based learning (PBL) methodologies (Chapter 1). The approach used can be defined as a blended mode, where the students upgrade and modify a preset scenario developed by the teacher. In the following the first project carried out with students using Ecocity island is described (Figure 3.A5.2).

Figure 3.A5.2. *Ecocity island. Students' work is depicted in the round photos.*

3.4. STUDY POPULATION AND SETTING

The activity was carried out with 28 K8 degree students from the school N, 24 of which answered the post-activity questionnaire (54.2% males, 45.8% females). Among the 24 students, 17 connected to the VW as avatars (70.8%) (group W) from their classroom during the school time. The other 7 cooperated to sort out information and make multimedia presentations and videos. While the researcher was online, their teachers supported them during their activity, in person, also evaluating the reaction of the students to the new activity and the level of attention during the project (group C). The 4-months project (from December 2021 to March 2022), implied periodical meetings for a total of 30 hours. They worked in teams composed of 5-6 students.

3.5. OVERVIEW OF THE PROJECT

A pre-activity questionnaire was delivered to students to probe the students' interest to the general theme proposed and to decide the specific topic to be developed. Students were invited to calculate their annual CF based on their real domestic consumption: transportation, energy for heating houses and electricity consumption, including the use of smartphone (e.g. data transmission). Then they imagined solutions (in terms of energy saving and new technologies) to reduce first their individual CF and then applying these solutions at large scale to a typical city. Students also studied the impact of renewable energy technology, such as solar panels and horizontal wind turbines on buildings, electric/solar chargers for electric vehicles and so on. During their work, students started to ask themselves about the impact of the production and use of smartphones in terms of carbon footprint: it was consequential, therefore, to also deepen the information regarding the critical minerals used in smartphones, their properties, and their environmental impact.

3.6. RESULTS

The experimentation was subdivided in steps, as described in the following.

3.6.1. Pre-activity test

Before starting the activities, a pre-activity survey was delivered to students, mainly aimed to know their digital skills and their possible knowledge about sustainability and carbon footprint. Of the 26 students responding to the survey, 69.2% and 65.4%, respectively, knew the definition of Sustainable development (according to the Brundtland Report, 1987) and the carbon footprint definition.

Moreover, in an open-ended question, students were asked to indicate the main characteristics a sustainable city should have. Answers were grouped into categories. From the answers analysis it emerged that the use of renewable energies and sustainable transportation are the most important factors that increase the sustainability of cities, in the perception of students (respectively 38.5% and 26.9% of the total students) (Table 3.A5.1).

In addition, students were invited to choose from a list of 14 "multi-select multiple-choice questions", the 5 most important factors/aspects that, in their opinion, contribute to increase the urban sustainability. The three aspects towards sustainability which obtained the largest consensus were: boost public transportation and reduce the use of fossil fuels (65.4%), building houses with technological materials, boosting recycling (65.4%), increase the energy efficiency of buildings (61.5%) (Table 3.A5.2).

The first answers chosen are those related to renewable energy and public transportation, confirming what reported for the open-ended questions. From the pre-activity survey it emerged that, in the perception of students, the use of renewable energies and sustainable transportation are the most important factors that can help increase the sustainability of cities. Therefore, based on the students' answers, the main topic to be developed was decided: systems and solutions to reduce the Carbon Footprint in the urban context.

In the following the detailed list of topics is reported, grouped in 5 categories, which were developed during the activity and then used for the post-activity students' assessment (knowledge test).

- **Sustainability** (Sustainable development and Agenda 2030 Goals)
- **Renewable sources** (Difference between renewable and non-renewable resources)
- **Electric consumption** (Energy consumption for transportation and household electricity consumption)
- **Carbon footprint – CF** (Definition, CF of electricity consumption, CF of the production and use of smartphones, CF of renewable energy equipment)
- **Systems and solutions for reducing the carbon footprint** - energy transitions (decrease in electricity consumption, photovoltaic panels, vertical wind turbines, electric mobility, solar charging electric power units, public transportation)
- **Critical minerals for technology and for the energy transition** (distribution, extraction, environmental impact)

3.6.2. Carbon Footprint calculation

Students used a custom online calculator adapted from an online source (https://www.carbonindependent.org/index.html) to calculate their domestic carbon footprint, as premise for future activities in the virtual world. This preliminary activity was proposed to students with the aim to make the concept of carbon footprint more practical and not purely theoretical (Weirs and Osborne, 2020), and to increase their awareness that every action, daily routine, has an impact in terms of energy consumed and greenhouse gases produced.

Table 3.A5.1. *Characteristic of a sustainable city (26 students)*

Characteristic	Students (%)
Renewable energy use	38.5
Sustainable transportation	26.9
Social policies	23.1
No pollution	23.1
General Sustainability	15.4
Cleanliness	15.4
Green Areas	11.5
Recycle	7.7

Table 3.A5.2. *Students' perception about the factors that increase urban sustainability*

Item	n. of students	%
Boost public transportation and reduce the use of fossil fuels	17	65,4
Increase the percentage of renewable energy	17	65,4
Build house with technological material, boosting recycling	16	61,5
Increase the energy efficiency of buildings	16	61,5
Increase urban green spaces	15	57,7
Guarantee decent work, reduce inequalities, health	10	38,5
Improve the waste management efficiency	7	26,9
Ensure inclusive and equitable quality education	7	26,9
Limit soil consumption, refurbishing old buildings instead of building new houses	6	23,1
Boost tourism	5	19,2
Improve internet connections	3	11,5
Zero km food	3	11,5
Increase the numbers of store or commercial centres	0	0
Make the public administration more efficient	0	0

3.6.3. Training

At the beginning of the activity in the Ecocity island, students were instructed on the objectives of the project and learned how to master avatar movements and communication and get acquainted with 3D modeling and the VW's the main tools (interact / import / build resources) (Lee, 2009). They used a graphical user interface downloaded at firestormviewer.org. (a viewer) to access to the world.

3.6.4. Information research

After choosing the topics for the project, the pupils searched, found and organized web information, to be used for multimedia presentations, 3D graphs and to plan the building activities. Students made 23 multimedia presentations working in small groups. The topics covered were: renewable energy (30.4%), minerals for energy transition and technology (21.7%), carbon footprint of electric consumption and the use of smartphone (21.7%), sustainable transportation (17.4 %) and Agenda 2030 Sustainable Development Goals n. 7 and 11 (8.7%). All multimedia presentations and infographics were imported in Ecocity to be placed near the 3D objects as they were built.

3.6.5. Building activity

Students translated the info collected in 3D objects to explain what they learned. The Collaborative learning and the Inquiry-based learning methodologies were used, letting students to find answers to driving meaningful questions and discussing together problems and solutions and the best way to display concepts, data and facts. Students also made some objects interactive by mouse clicking, to give more information. During the activity the students set up the following final products:

- A house displaying the electric power and the carbon footprint for 1 kWh of energy consumed (g CO_2/kWh). Clicking on the various appliances and imputing the time of usage, their carbon footprint was obtained.
- Solar charging electric power units
- Solar-covered parking lots

- Houses with horizontal wind turbines, solar thermal collectors and photovoltaic panels
- A smartphones store, where students collected all information about the carbon footprint of the production and use of smartphones (Mattila et al, 2014) and the critical mineral used (lithium, cobalt, indium, rare earth elements and so on). A particular focus was devoted to their properties, uses and environmental impact (Koltun & Tharumarajah, 2014; Talens Peirò & Villalba Méndez, (2013); Farjana et al., 2019).
- A wood, representing the number of trees to be planted to offset their carbon footprint. Several multimedia presentations, 3D graphs and info panels were placed near the objects to give more information.

In Figure 3.A5.3. there are some examples of environments and products built by students.

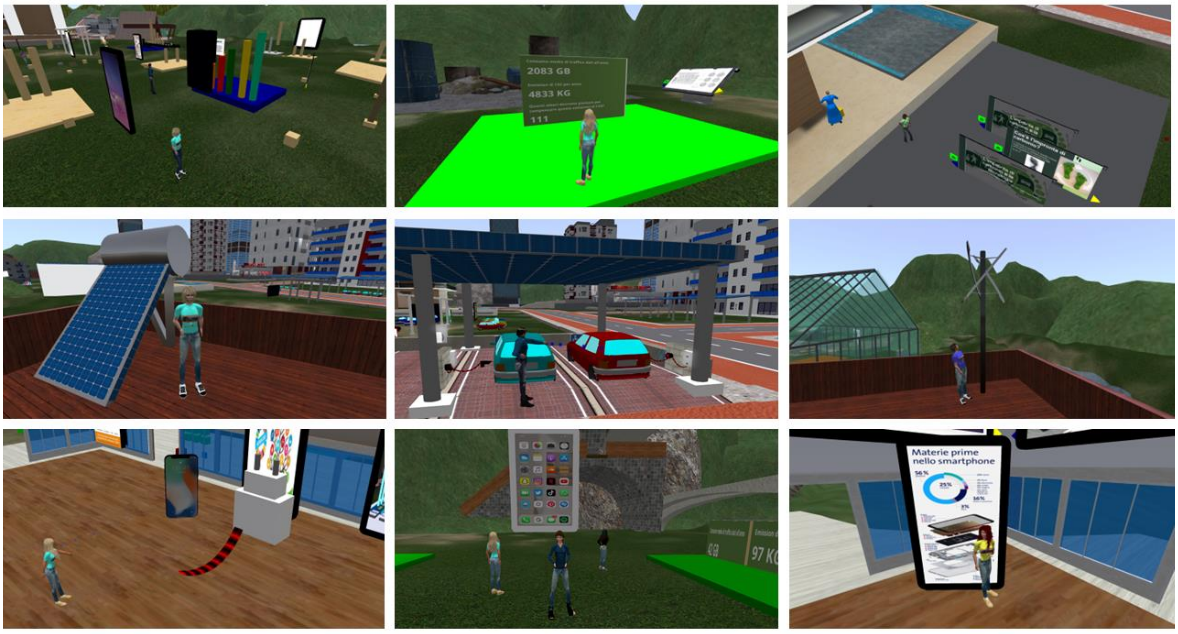

Figure 3.A5.3. *Topline: Students set information (from the left: 3D graphs, panels, screens for multimedia presentations). Middle line: Solutions to reduce the carbon footprint (from the left: a solar water heater, a solar electric charger for cars; a vertical wind turbine). Bottom line: The carbon footprint of technology (from the left: CF to charge a mobile phone, graph of data transmission CF, CF of mobile phone production, related to critical minerals.*

3.6.6. Screen casting

Using screen capture, students' teams made videos to explain all they have done and learnt (storytelling), improving soft skills while they wrote dialogues highlighting relevant information with the proper terms (communication skills). In the videos students explained the activity steps, displayed the 3D objects and a brief summary of the content.

The final videos made by the teams can be seen at:

- https://www.virtualscience.it/video/3E-nettuno1_ambienti_immersivi.mp4
- https://www.virtualscience.it/video/Ecocity_DN.mp4
- https://www.virtualscience.it/video/Ecocity_SL.mp4
- https://www.virtualscience.it/video/Ecocity_EIG.mp4
- https://www.virtualscience.it/video/Ecocity_DS.mp4

3.6.7. Assessment

At the end of the activity, the students' artefacts (3D objects, videos and multimedia presentations) and information have been evaluated by the teachers and researchers in terms of correctness, clarity and originality. The quality of the works and the contents produced revealed a high level of involvement and concentration of the students. In addition, a knowledge test, a take-home messages section and a satisfaction survey were administered to students. Reliability for the knowledge test is .89.

3.6.7.1. Knowledge test

A 36-score knowledge test was administered to the students to evaluate their learning acquisition, coverings the same topics investigated by the students' research (Table 3.A5.3). In Annex 3.A5.2. the results of the knowledge test for each student are reported, grouped by topics.

Table 3.A5.3. *Post-activity test results (global and by categories)*

Topics categories	Detailed topics	N° questions	Mean score (%)	STD
Sustainability	-Sustainable development -Agenda 2030 Goals	3	86.1	
Renewable sources	-Difference between renewable and non-renewable source of energy	8	80.7	
Electric consumption	-Energy consumption for transportation -Household electricity consumption	5	66.7	
Carbon footprint (CF)	-Definition of CF -CF of electricity consumption -CF of the production and use of smartphones -CF of renewable energies equipment	7	72.6	
Systems and solutions for reducing the carbon footprint (energy transitions)	-Decrease in electricity consumption -Photovoltaic panels -Vertical wind turbines -Electric mobility -Solar charging electric power units -Public transportation	7	78.0	
Critical minerals for technology and for the energy transition	-Physical Properties / Characteristics -Uses -Environmental impact	6	77.1	
Global mean score (Total respondent students = 24)		36	76.5	18.5
Mean score group W (n. = 17)	Test U Mann Whitney	36	81.9	16.8
Mean score Group C (n. = 7)	P value (W / C) = 0.016	36	63.5	16.6
Cronbach alpha = .89				

From the analysis of the results, a significant difference (at 95% level) of the mean test score between students who accessed the world as avatar and those who just searched and elaborated information emerges, as determined using the U Mann-Whitney test, a statistical test useful to compare two independent groups that do not require large normally-distributed samples. As explained in the discussion, the difference could be related to the building activity of the students who accessed the VW, which helped them to foster learning.

3.6.7.2. Take-home messages

In addition to the post-activity questionnaires, in an open-ended question, the students were asked to indicate 3 “take-home messages” of the activity. The answers obtained were grouped in categories. The six most indicated messages are reported in Table 3.A5.4.

Table 3.A5.4. *Students’ “Take-home messages”*

TOPIC	% STUDENTS
Sustainability (general concept)	45.8
Rare earth elements and technology	41.7
Renewable energy	41.7
Saving energy	37.5
Carbon footprint of electricity production and use of electronic devices	29.2
Public Transportation	8.3
Don't know, don't answer	8.3

Note: 24 respondent students

The topic regarding the Rare Earth Elements (critical minerals), chosen by students during the project, was object of one of the preferred take-home messages. This choice highlights the importance of the active involvement of students in the topics’ choice, especially those close to their everyday life. Students were impressed by the importance of Rare Earth Elements in technology and how much their extraction and exploitation are disrupting in terms of carbon footprint and environmental impact.

3.6.7.3. Satisfaction Survey and digital skills

A more general evaluation of the activity was based on the students’ satisfaction survey (section 3.S and Annex 3.S.5a), demonstrating that students judged positively their experience, in terms of learning experience and ease of use. More details are reported in section 3.S. and Annexes 3.A5.a and 3.A5.b.

3.7. DISCUSSION

Regarding the knowledge test it is interesting to note that, although the activity was carried out in the classroom and all students had access to the same information tools (web research, multimedia presentation), students who accessed the world got better results in the knowledge test. This means that the act of building, transforming information in 3D objects, enhanced active learning and promote reflection according to the Inquiry-based learning or problem-based learning approach (Hmelo-Silver, 2004).

Through the building of new 3D artefacts students can express and share their ideas or solutions, discussing together about the better way to implement solutions to various problems (co-constructing) (Koutsabasis et al., 2012). Also, virtual worlds, thanks to their simulation capability, foster students’ creativity (Alahuhta et al., 2014), as they recreate or envision sustainable solutions in 3D. The modification of the environment by the students (creating new objects or modifying an existent one) can be seen by other users in real time allowing immediate feedback and enhancing collaboration (Vosinakis et al., 2011).

Results of knowledge tests and the analysis of their 3D objects and contents, demonstrate that students increased their awareness towards the need of an energy transition to renewable sources and a more sustainable use of technology. Regarding the ICT skills, multiple digital and soft skills can be developed making activity in virtual worlds using 3D modeling, image editing, video editing and production, basic programming (Annex 3.A5.a).

3.8. CONCLUSIONS

Ecocity is didactic activity carried out on the Opensimulator-based virtual world Techland, in a new island focused on sustainability to address the students' attention to the environmental impact of technology and energy production. All didactic materials produced during the experimentation is now placed in the island and available for all students and teachers visiting Ecocity.

This activity is the demonstration that complex topics, for the age group considered, such as energy transition and critical minerals, can be developed with satisfactory results in a motivating environment and with the proper methodologies.

The calculation of the personal carbon footprint and the knowledge of the carbon footprints of the main production processes of electronic devices has increased the students' awareness of the finite value of georesources, the impact of technology, and of the need to immediately adopt solutions to mitigate climate change.

3. A6. My sustainable city

Figure 3.A6.1. *Summary of the project*

3.1. AIMS OF THE PROJECT

This experimentation was part of a broader project coordinated by Indire (the National Institute for Documentation, Innovation and Educational Research of the Italian Ministry of Education), called Mineclass and aimed at primary and secondary school teachers (Benassi et al., 2021). Its goal is to provide the teachers with remote training and support for the implementation of educational activities designed on Minecraft (Education Edition version) compatible with the existing school curriculum. Due to the Covid-19 pandemic, the Indire project has undergone changes, passing from a totally face-to-face teaching to an exclusively remote or mixed one.

3.2. TOPIC ADDRESSED

This project focused on urban sustainability. The Agenda 2030 Sustainable Development Goal no. 11 (SDG no. 11 - Sustainable cities and communities) is crucial for the fight to climate change because, by 2030, urban areas are projected to house 60% of people globally and most of the georesources and energy are used in cities (United Nations, 2018). In addition, Agenda 2030 recognizes the critical role of education as a catalyst for broader change (SDG no. 4 - Quality Education). So, Minecraft can be a useful tool to engage students, to let them imagine and build their ideal city, to reflect about their lifestyle as urban citizens. In fact, Minecraft is also used for engaging young students and community members in citizenship activities, as in the project by the "Block by Block" Foundation, where students rebuilt their ideal city or start new structures in an already existent city (Block by Block Foundation, 2021). Also Rexhepi et al. (2018) described a combination of a game-based learning and co-creation of public services using a scenario based on Minecraft to involve young people.

3.3. DESCRIPTION OF THE LEARNING SCENARIO

The initial scenario was setting as void. The aesthetic appearance was an infinite expanse of grass to be built on. Students divides the space in zones, one for each team, destroying blocks along the perimeter of the zone to have a visible dark line (Figure 3.A6.2).

Figure 3.A6.2. *An overview of "My sustainable city" under construction*

3.4. STUDY POPULATION AND SETTING

The activity was carried out with 25 K8 students of the school N (68% males, 36% females), 13 of whom entered in the Minecraft platforms (84.6% males, 15.4% females) and 12 students were involved in a traditional lecture (41.7% males, 58.3% females).

This work was carried out by the authors in mixed mode, between November and December 2020. To date, very few synchronous projects have been conducted remotely: generally, collaborative projects in Minecraft Education Edition with underage students have been carried out in person or asynchronously. An online server with a Windows operating system was used, where Minecraft Education Edition application could be enjoyed by several users at the same time in collaborative learning mode. Access to the virtual world took place both from the classroom, during the school time and in the afternoon, and from the students' homes. The in-world activity was also supported by the Institute's Microsoft Teams platform for briefing and sharing ideas.

3.5. PHASES OF THE PROJECT

The control group was involved in a 2-hours video lesson in sharing screen mode focused on the same topics of the experimental group. In his paper, Alawajee, (2021) found that in only 19% of the papers reviewed a control group was used. However, we preferred to perform a study more quantitatively than others in the literature, therefore we introduced a control group to better compare the results obtained from the school experimentation.

The experimental group was composed of four teams of 3-4 K8 students, who were asked to build a model of a sustainable city accessing Minecraft (Education edition) from home, independently organizing the division of tasks and times. A maximum time of one month was fixed to complete the assignment. Students were asked to create a building/structure/service using the following sustainability criteria: suitable building materials, waste management, renewable energy, systems to save domestic water and energy, zero Km food, sustainable transportation.

Periodical meetings were scheduled by the teacher to verify the project advancements, giving support and suggesting new activities, with the following scheme:

- 1 two-hours online meeting during school time for the first approach to urban sustainability and the objectives of the Agenda 2030 (initial lesson). The objectives of the project were designed, and the main features of the Minecraft Education Edition (MEE) were highlighted to the students
- 6 two-hours online meetings on Minecraft (from school or home) for designing, planning and building activities. In Figure 3.A6.2 the city under construction is shown
- 1 online meeting from school, where students involved reported about their projects, the Agenda 2030 goals developed, the problems encountered and solution founded (dissemination)

In addition, students were free to access Minecraft from home, alone or in team, to continue the building work or from the classroom under the supervision of one of the authors. Among the topics proposed, their work was focused on reducing products consumption and saving energy and water, the use of green urban transportations, the production and use of renewable energy. In Figure 3.A6.3 the workflow of the project is displayed.

3.6. RESULTS

3.6.1. Final products

Pupils presented their work via videoconference, in the classroom, during normal school hours (at that time restrictions due to Covid-19 pandemic had temporarily ceased and it was possible to attend school). Their own science teacher Raffaella di Palma was also present. One student from each group presented their work in screen sharing directly from the Minecraft world. Here the teams highlighted the sustainability elements of the project and which of the Agenda 2030 goals they wanted to highlight (Annex 3.A6.1). Videos can be seen at:

- https://www.virtualscience.it/video/palazzo_arcobaleno_red.mp4
- https://www.virtualscience.it/video/bosco.mp4
- https://www.virtualscience.it/video/stazioneautobus.mp4
- https://www.virtualscience.it/video/villa_eco.mp4
- https://www.virtualscience.it/video/minecraft_ICnettuno1.mp4

Figure 3.A6.4 displays some buildings/services created by the pupils.

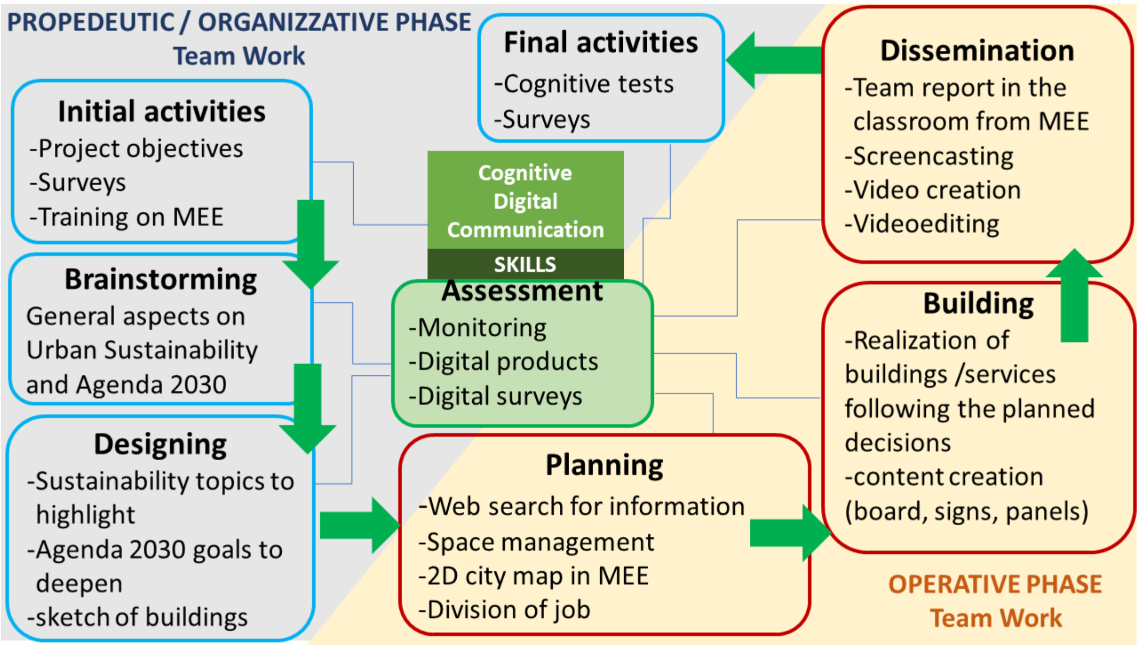

Figure 3.A6.3. *Workflow of the project*

Figure 3.A6.4. *An overview of the sustainable city in Minecraft. From left to right, from top to bottom: The vertical forest tower in Milan, a sustainable Hotel, example of a sustainable bus station, renewable energy from wind, an organic garden, a recycling station.*

3.6.2. Knowledge test

At the end of the project activities, a test was delivered to both groups, with questions about carbon footprint, transportation, smart buildings and energy. The results showed the achievement of very good results for the experimental group respect to the control group (75.2 vs. 56.9%, Table 3.A6.1), suggesting that the activity was useful to acquire a deeper knowledge about the topics proposed during the project and make the students more aware about sustainability. In Table 3.A6.1 the test results are summarized.

Table 3.A6.1. *Test Results.*

	Experimental Group	Control Group
Mean test score (%)	75.2	56.9
Standard Deviation	10.1	16.9
p Value	<0.01	

Also, an open-ended question was administered to investigate the students' perception of the concept of "sustainable city". Pupils were asked to answer the question: "In your opinion, what are the main features of a sustainable city?" The open answers were grouped into thematic categories reflecting their opinions (Table 3.A6.2). The post-activity questionnaire is in Annex 3.A6.2.

Table 3.A6.2. *Main features of a sustainable city in the student's opinion. Results are expressed in % students.*

Main features of a sustainable city	Experimental Group (n. 13)	Control Group (n. 12)
Sustainable Transportation	84.6	46.2
Urban green areas	76.9	50.0
Innovative and sustainable buildings	69.2	46.2
Saving energy / Renewable energy	61.5	30.8
Social aspects (No poverty, Quality education, gender equality, decent work, dialog with government, socialization…)	53.8	15.4
Sharing object and service / reduce the underutilization of buildings	46.2	30.8
Recycle and waste management	46.2	15.4
Saving Geo-resources	38.5	30.8
Reducing pollution and carbon footprint	30.8	8.3
Clean and well-kept city / respect for the environment	0.0	38.5

The open-ended questions revealed that experimental group highlights more features and suggests more technical and practical solutions respect to the control group, which used more generic terms as "respect of the environment" or "a clean city".

The activities and the behavior of the experimental group during the project was also assessed by the researchers/teachers by monitoring their behavior during the activity on line, the way they collaborated and the digital products created and presented by the students. Informal interviews to the students were carried out during the project, to report about the project developments with time. Partial results of this experimentation have been published (Occhioni & Paris, 2021).

3.6.3. Students' satisfaction survey and digital skills

A satisfaction questionnaire was also administered to the experimental group to inquire about the acquisition on new digital skills and their grade of satisfaction. Students declared to have improved their digital and technical skills and appreciated the project. More details are reported in section 3.S.

3.7. DISCUSSION / CONCLUSIONS

From the analysis of results, it emerged that the use of Minecraft has been effective and meaningful for learning in a more motivating way and for various reasons, respect to traditional teaching:

- it favored the implementation of creative and constructive solutions arising from the creativity of the students and from the mediation of all the contributions of the team
- it promoted the collaborative approach to problems and the development of problem-solving attitudes
- it introduced the students to the use of new forms of communication thanks to the final project report carried out using storytelling and data documentation

The results helped the students to open to new scenarios on how to improve urban sustainability topics, leaving students free to build their own learning path and to be active actors in the organization of their knowledge.

ACKNOWLEDGEMENTS

Thanks to Indire (Italian National Institute for Documentation, Innovation and Educational Research) for the support during this experimentation and the use of Minecraft Education licences.

3. S. Satisfaction survey

3.1. INTRODUCTION

Knowledge tests administrated to students in every activity have been important to highlight their global quality in terms of knowledge gain, for each type of platform and methodological approach. Nevertheless, satisfaction surveys help us to evaluate the students' experience regarding the:

- Quality of the learning environment (scenario)
- Learning experience
- Ease of use of the platforms
- Students' perception of acting in virtual worlds
- Students' perception of using virtual worlds as distance learning tools, especially during crises like the Covid-19 pandemic

Satisfaction questionnaires are very similar for all the activities, so they are discussed all together in this chapter. They were and were adapted from Chou et al. (2005), Contreras-Mendieta et al. (2018) and Rosmansyah et al. (2019). Some specific questions are related to the specific approach (IBL or GBL) or to the period of experimentations (e.g. during the restrictions of the pandemic or not) and are related only to one or few activities. Generally these questionnaires are 5-points Likert scale statements of the following type:

- (Likert scale: 5 = Strongly Agree; 4 = Agree; 3 = Neutral / Undecided; 2 = Disagree; 1 = Strongly Disagree. The statements labeled with (*) are reverse scored.
- Likert scale: 1 = Extremely; 2 = Very; 3 = Moderately; 4 = Slightly; 5 = Not at all.

In Annexes 3.S.1, 3.S.2, 3.S.3, 3.S.4, 3.S.5a, 3.S.5b, and 3.S.6 the satisfaction surveys of all the activities are reported in detail, which display median, mean, standard deviation of the mean, and percentage of Likert levels 1-2, 3, 4-5. Here some common considerations and key points are discussed, using the mean values to compare results of each activity.

3.2. QUALITY OF THE LEARNING SCENARIO

The questions relative to this issue are related to the activities A2, A3, A4 that were carried on according the game-based learning approach. In facts the educational paths (scenario) were built by the researchers while students had to accomplish missions and tasks.

From Table 3.S.1 it emerges that students globally appreciated scenarios (3D educational items and information presented in the islands, with no statistical difference between the groups S and W of the activity A2 (see Annex 4.2). Students judge the contents as clear and explanatory especially for the Sustainability Hub islands, probably because topics developed in activity A3 and A4 (critical minerals) were more specific. So, we decided, in the following experimentations, to increase the time devoted to the activity or to have two levels of deepening, with an initial approach with the key concepts and the possibility to deepen them if necessary. Generally, a bit lower scores were obtained regarding graphics and aesthetic of the scenario. Opensimulator game engine could appear a bit archaic to students who are used to play with all sort of videogames; moreover, a web-based virtual worlds can't have a "level of details" too high, in order to be supported by various devices.

Table 3.S.1. *Quality of the learning scenario*

Activity	A2-S	A2-W	A3	A4
Approach	GBL	GBL	GBL	GBL
Platform	O	O	F	O
Number of students	439	136	101	16
Statements				
The educational path is well organized and structured	4	4.3	3.8	4.1
The scenario is pleasant (graphics and colors / aesthetic)	3.3	3.7	3.7	3.4
Information in the island is clear and explanatory	4	4.2	3.7	3.6
The 3D learning objects and graphs helped me to understand concepts and data	3.9	4.1	/	/
On-line games are suitable for learning	/	4.3	3.6	3.4
Different sections of the scenario were clearly labeled	/	3.7	3.9	4.1

Platforms: F= FrameVR, M = Minecraft EE, O = Opensimulator
Likert scale: 5 = Strongly Agree; 4 = Agree; 3 = Neutral / Undecided; 2 = Disagree; 1 = Strongly disagree.

3.3. LEARNING EXPERIENCE

Students positively judged all the activities in terms of knowledge gain, learning focus, engagement and enjoyment (Cleto et al., 2022). In particular for the activity A2, interactive 3D objects help students to better understand concept and data (Christopoulos et. al, 2014). In A2 activity there is a significant difference between the S group and the W group (see also Annex 3.S.2). Similar results were obtained also by Rosmansyah et al. (2018) for GBL activities in virtual words as activity A2. For all the activity with the IBL approach we evaluate also the improvement of digital skills, especially analyzing the final products (videos and 3D objects). In particular for the activity A5 the control group (C), who didn't access to the virtual worlds has a lesser perception of their improvement of digital skills respect to the students' who has actively participate to the building activity (Table 3.S.2). In fact, they also state how that activity was important to better retain information better established some concepts on the subject. It is also interesting to note how the group who participated the Minecraft activity (A6) showed the lowest score for the improvement of digital skills. It is due to the fact that (as it emerges in the pre-activity survey) students were already very acquainted with Minecraft, as the play also at home for entertainment.

3.4. EASE OF USE

At the beginning of each activity students were asked to rate their level of mastering of the 3 virtual world platforms used. It emerges that at least 94% of the students of the age range considered have none/poor knowledge of the use of Opensimulator and FrameVR platforms. On the contrary only about 30% of the students have none/poor knowledge of Minecraft (Figure 3.S.1).

Table 3.S.2. *Learning experience*

Activity	A1	A6	A5 W	A5 C	A2 S	A2 W	A3	A4
Educational approach	IBL	IBL	IBL	IBL	GBL	GBL	GBL	GBL
Platform	O	M	O	O	O	O	F	O
Number of students	8	13	17	7	439	136	101	16
Statements								
This activity increases my knowledge	4.4	4.2	4.5	4.6	3.9	4.3	3.9	3.8
This activity increases my learning focus	4.3	4.7	4.8	3.9	4.1	4.4	3.8	3.8
This activity gave me engagement and enjoyment	4.4	4.7	3.9	3.1	3.7	4.3	3.8	3.8
This activity improved my digital skills	4.4	3.6	4.5	3.6	/	/	/	/
I felt comfortable doing hands-on activities in the virtual world	4.0	3.9	4.1	/	/	4.3	4.0	3.6
The building activity helped me to better retain information and concepts about the subject	4.1	4.2	3.9	/	/	/	/	/
Inside the virtual world I felt engaged in the building activity	4.9	4.9	4.3					
Designing a city gives an overview of environmental sustainability and highlights which problems a technician/engineer has to face	/	4.2	/	/	/	/	/	/

Platforms: F= FrameVR, M = Minecraft EE, O = Opensimulator

Likert scale: 5 = Strongly Agree; 4 = Agree; 3 = Neutral / Undecided; 2 = Disagree; 1 = Strongly disagree.

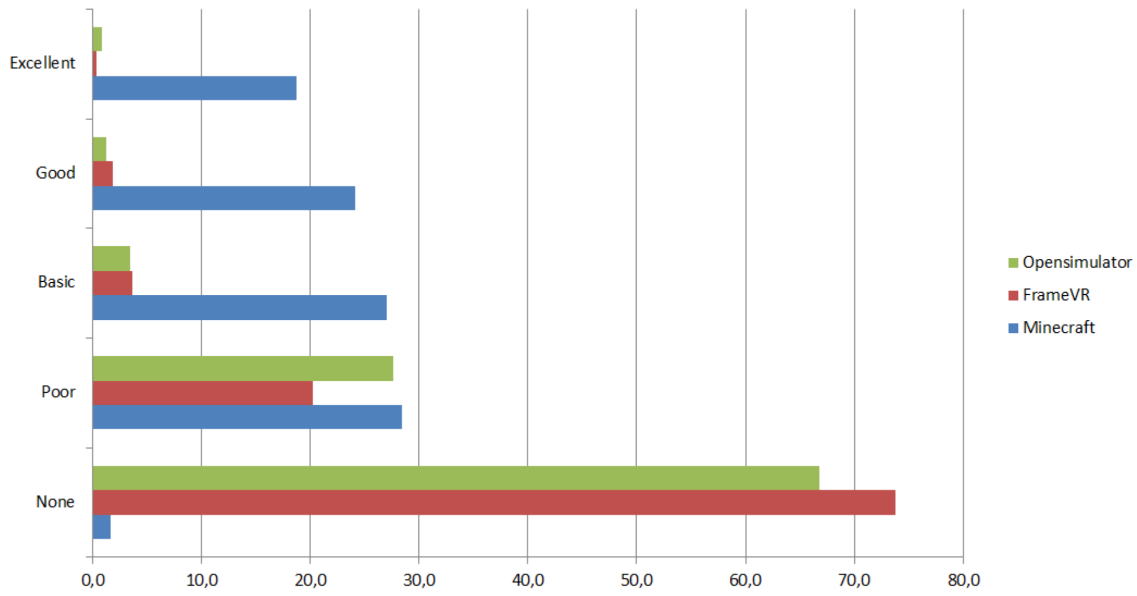

Figure 3.S.1. *Knowledge of the virtual platforms (students)*

For this reason, in the post satisfaction survey only students who used Opensimulator and FrameVR were asked to rate the level of difficulty they experienced during the activity. Findings about the ease of use are shown in Table 3.S.3.

Table 3.S.3. *Ease of use of the Opensimulator and FrameVR platforms*

Activity	A1	A5 W	A2 W	A3	A4
Educational approach	IBL	IBL	GBL	GBL	GBL
Platform	O	O	O	F	O
Number of students	8	17	136	101	16
Statements					
I have experimented difficulties about:					
Internet connection	4.1	4.1	4.4	4.1	4.3
Pc requirements	3.8	4.5	4.6	4.3	4.1
Communication with other avatars	4.8	4.4	4.5	4.2	4.2
Movement of the avatar	4.9	4.4	4.4	3.9	3.9
Interaction with objects (open online games, browse multimedia presentation, use 3D objects…)	4.5	4.5	4.3	4.2	4.2
Avatar customization	4.4	4.0	4.2	4.3	4.3
Teleporting	4.5	4.8	4.5	4.4	3.9
Taking pictures	4.5	4.3	4.3	/	/
Uploading images	4.1	4.4	4.2	/	/
Movement of the camera (zooming in and out. changing perspectives, and so on…)	4.8	4.6	4.3	/	4.3
Managing inventory	4.1	4.6	4.2	/	4.2
Building	4.5	4.8	/	/	/

Platforms: F= FrameVR, M = Minecraft EE, O = Opensimulator
Likert scale: 1 = Extremely; 2 = Very; 3 = Moderately; 4 = Slightly; 5 = Not at all.

By means of questionnaires delivered to the students at the end of the project emerge that they found no particular difficulty in act and interact in the world, to use the main features of the platform and to communicate with other avatars / students (Contreras-Mendieta et al., 2018). Note that, before each activity, a session of training was carried out.

3.5. ADVANTAGES / DISADVANTAGES OF VIRTUAL WORLDS

Students of the activity A2 (that represents the largest proportion of the students and encompass also most of the students of the other activities) were also asked to state if virtual worlds give advantages in education and distance learning (open ended questions). In Figure 3.S.2, the summary of their answers, grouped in categories by content analysis, is displayed. The questions were in general related to determine the perception of advantages or problems related to the use of virtual worlds and the learning about sustainability topics through this activity.

Figure 3.S.2 shows that both students' groups state that virtual worlds are fun and captivating, facilitate learning and can help to increase sustainability awareness. In addition, for both groups

although especially the VW group, virtual words helped them to feel near their classmates as they were there in COVID-19 lockdown, so they appreciated this opportunity to interact with their classmates. Students of the VW group also stressed that the use of virtual worlds can improve their ICT skills. Even the Sharing-Screen group were positive with this activity highlighting there are advantages in this type of lessons.

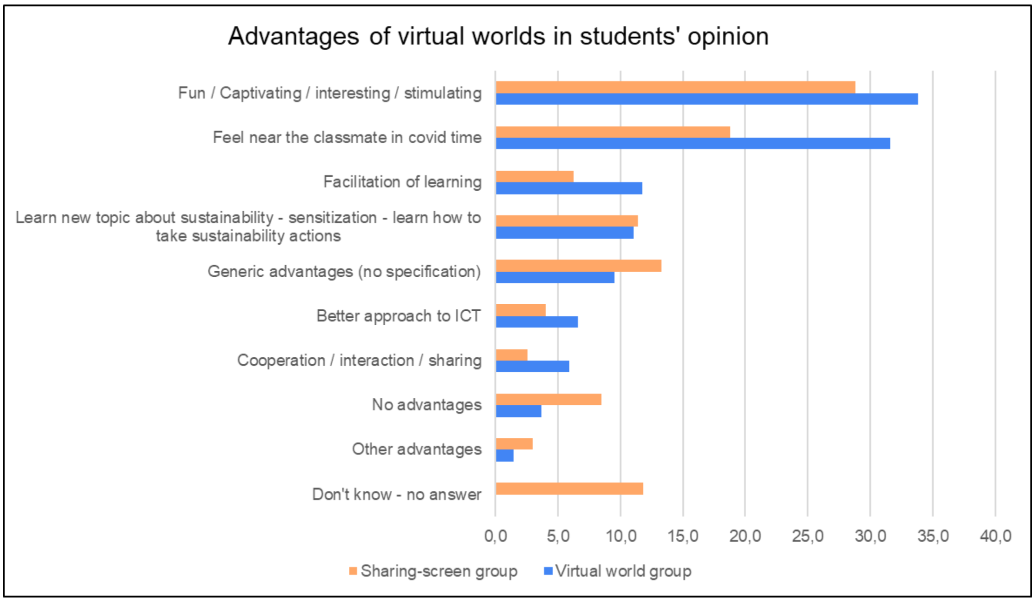

Figure 3.S.2. *Results of the open-answers questions of the students' satisfaction questionnaire about the use of virtual worlds in distance learning, expressed as a percentage of responses from the total number of pupils in each group.*

In the following, some of the students' statements from both groups are reported as examples:

"Using this virtual world was more fun and pleasant to understand the concepts related to sustainability, also because it is possible to go exploring to find games and activities to do. Even if we are in distance learning, it was still a nice experience".

"In my opinion, using a virtual world of this kind for distance learning is very innovative and appealing and make school fun and interesting".

"Although I'm not a big fan of this program, I must say it was a different experience from the usual video lesson and involved us more than usual. In my opinion, using a video game (or a virtual world) for teaching (not only when we are at a distance), could involve more students than the normal lesson if, of course, the game is well developed".

"In my opinion a virtual world of this kind can help to be closer, especially in this period, because it is a way to communicate more and to practice educational experiences despite the distance".

"I really liked to participate in this experience also because I could communicate and build together with my classmates when we wanted and not necessarily just during the lesson. It was a very nice experience, which helped me to have fun during the months of Covid-19 lockdown"

After 1 year the same optional question about the advantages and disadvantage of virtual world was proposed to 101 students of the school F who participate also at the A3 activity (FrameVR), asking also about any disadvantages. In Figure 3.S.3 results are reported.

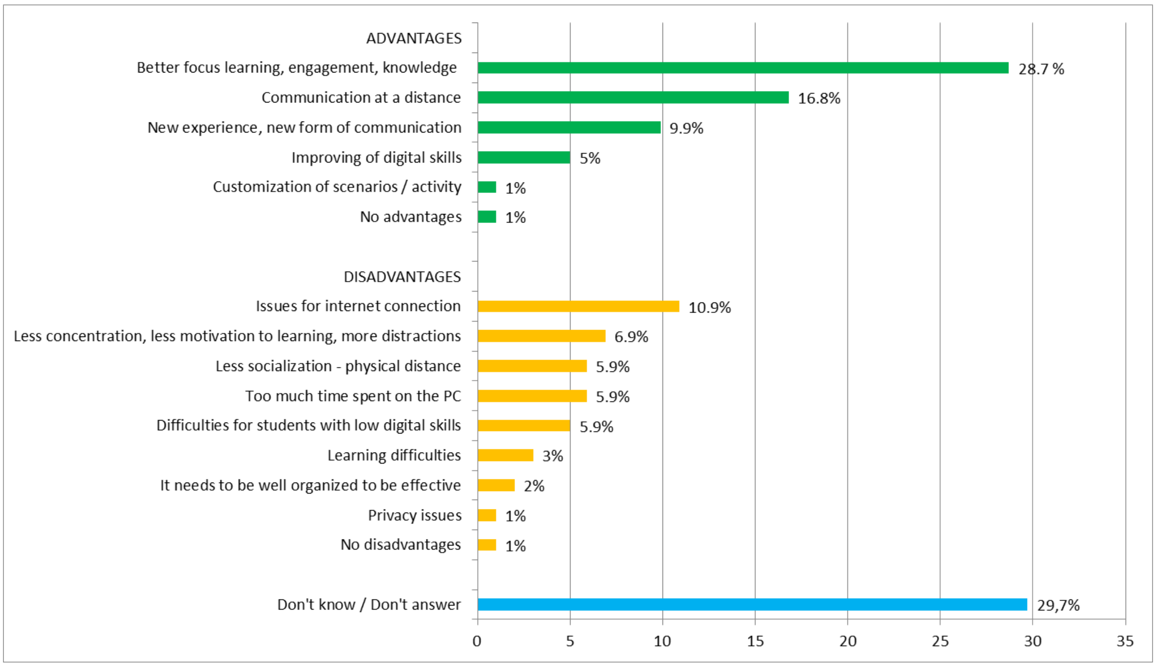

Figure 3.S.3. *Advantages and disadvantages in using virtual worlds in distance learning*

Generally students perceived virtual world as engaging environments giving better focus and knowledge, but others thought they are source of distraction and less concentration. They also appreciated the fact to use the world everywhere (although they experiment it in the classroom), as a new form of communication. On the contrary, some students highlighted the lack of physical contact with classmates in distance education, and too much time to spend at the PC. In addition, students were aware how a good internet connection is important to have a good learning experience, especially in the movement of the avatar. From the students' answers we can deduce that virtual worlds are valid tools to teach, as alternative to videoconference, or in the computer laboratory, so students can stay together.

In addition to activity A2, also the activities A1 and A6 were carried out during the Covid-19 lockdown, so students' accessed at the virtual words from home. For these activities, a statement related to the students' perception to feel near their classmates during the Covid pandemic (by means of the activity itself) was administered ("*Inside the virtual world I felt near my classmates despite the pandemic"*) as both obtaining a mean of 4.5 of the Likert scale (from 1 Strongly disagree to 5 Strongly agree) (Annex 3.S.1 and, 3.S.6).

4. Discussion

In this chapter the main results of the research are discussed, also taking into account the new sustainability competence framework by the European Union, the GreenComp. In Chapter 3 for each section A1-A6 specifically related to each activity, a discussion regarding the specific topics of the experimentation have been already done. Therefore, this chapter had been dedicated only to more general issues and considerations.

4.1. THE GREENCOMP: TOWARDS A NEW DEFINITION OF SUSTAINABILITY

The importance of personal behaviors and lifestyles were stressed by in the recent GreenComp, the European sustainability competence framework, developed to “support all educators and learners in embedding environmental sustainability topics into all educational systems and curricula in Member States” .One of the main features of the GreenComp is that “was written for all learners, irrespective of their age and their education level and in any learning setting – formal, non-formal and informal”. Its principal aim is “to foster a sustainability mindset by helping users develop the knowledge, skills and attitudes to think, plan and act with empathy, responsibility, and care for our planet” (Bianchi et al., 2022). After an initial literature review by Bianchi (2020) and Scalabrino (2021), a group of approximately 75 experts and stakeholders was consulted to provide relevant feedback and to progressively reach an agreement on the list of competence identified.

This framework was not available at the time this research project started (2019), therefore it is interesting to determine how many of the general ideas which stimulated this research and brought to the results of the experimentation, can now find a larger scheme where they can be inserted and find useful comparison and schematization.

The GreenComp consists of 12 competences - Knowledge, Skills, Attitudes (Crick, 2008) (reported in italics in the following list) - organized into four areas (in italics), all interrelated and interconnected:

1. *Embodying sustainability values*
    a. **valuing sustainability**
    b. **supporting fairness**
    c. **promoting nature**
2. *Embracing complexity in sustainability*
    a. **systems thinking**
    b. **critical thinking**
    c. **problem framing**
3. *Envisioning sustainable futures*
    a. **futures literacy**
    b. **adaptability**
    c. **exploratory thinking**
4. *Acting for sustainability*
    a. **political agency**
    b. **collective action**

c. **individual initiative**

In comparison to the learning objectives described in chapter 1 for the present research and related to the SDGs Goals, the GreenComp framework is a more general guideline. However, it is necessary to point out that knowledge, skills and attitudes in the GreenComp are intended as life-long learning competence, so they should be placed in relation to the age of the pupils. Therefore, in light of the competencies outlined in the GreenComp, the main competencies fostered in pupils in the frame of this research for each learning scenario have been broadly summarized in Figure 4.1.

It is interesting to note that in the GreenComp the meaning of Sustainability is used as strictly related to the Earth's resources and the planetary boundaries: "*Sustainability means prioritising the needs of all life forms and of the planet by ensuring that human activity does not exceed planetary boundaries"*. The attention on georesources and the role of geosciences in education is therefore highlighted, and it is also evident the need to plan learning paths related to georesources and their use as early as low secondary school, similarly to those described in this research.

The GreenComp framework is one of a series of guidelines that derive from the European Green Deal (European Commission, 2019), a roadmap that European Union is pursuing to become carbon neutral in 2050 by improving "the well-being and health of citizens and future generations" by providing:

- fresh air, clean water, healthy soil and biodiversity
- renovated, energy efficient buildings
- healthy and affordable food
- more public transport
- cleaner energy and cutting-edge clean technological innovation
- longer lasting products that can be repaired, recycled and re-used
- future-proof jobs and skills training for the transition
- globally competitive and resilient industry"

(https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en#documents)

In this picture, the fundamental topics indicated by European policy about sustainability appear to be well focused by this research project, where the approach to carbon footprint, energy and georesources were well addressed, specifically or as a part of urban sustainability activities. In a modern view about the role of geosciences in the global picture about sustainability, everything is interconnected: exposing pupils to learning scenarios where this interconnection is evidenced is in line with the GreenComp indications, but also with the indication regarding the teaching contents of the *Environmental and civic education course* in the Italian schools.

Moreover, Figure 4.1 well evidence that importance given in the learning activities of this research to "recognize that everyday action matters" even at the personal level and that "every action has environmental, social, cultural and economic impacts". The focus given to these aspects are relevant to improve a widespread environmental awareness and culture for sustainability: this approach acquires a high value especially considering the target age range of the activities proposed here, where the students can also vehiculate good practices and behaviors in their families, becoming change-maker in their social environment.

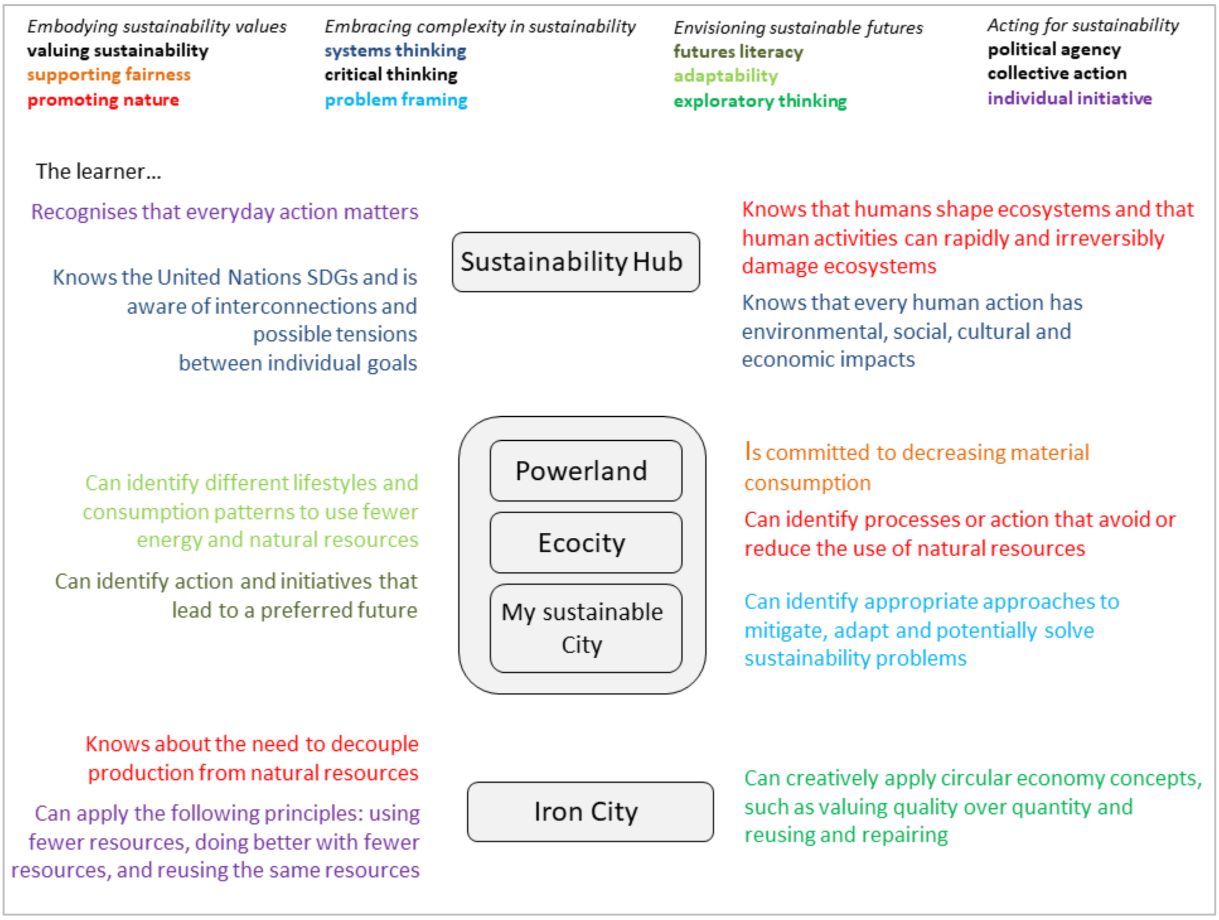

Figure 4.1. *For each learning scenario of this research, the GreenComp competence are reported in different colors, same reported for the Knowledge, Skills and Attitude*

4.2. LEARNING OUTCOMES

Regarding the assessment of students' outcomes, Redman et al. (2021) proposed three main tools: self-perceiving, observation/performance, and test-based approaches, on the basis of a literature review. While knowledge competences are relatively easy to assess with test-base approaches, is more difficult is to evaluate behaviors and agency of students that need to set up practical activity, related to real problems. So require educational paths strictly related with the civil society, and approached with IBL or PBL (Wiek et al., 2014).

Given the restrictions due to the pandemic, mainly knowledge competences were assessed. GBL activities (A2a, A2b, A3, A4) was carried out in a short time (2h). This time was enough to assess the knowledge competence but, to evaluate skills and behaviors towards sustainability, IBL activities (A1, A5, A6) were more effective (20 -30 total hours). VW made it possible to assess some more specific skills related to the ability to find solutions to common problems or imagine a sustainable future. This is thanks to the analysis (observation/performance) of the final products (3D models, videos) produced by the pupils and the solutions put in place, for example, to reduce their carbon footprint or save resources.

Regarding the knowledge competences, that activities were therefore devoted to individuate main topics to be able to evidence some clear take-home message for students:

- The awareness of our planet's limits

- The need to lower the Carbon footprint, starting from the daily routines
- Technology and research already have important solutions to reduce energy consumption and carbon footprints
- The energy transitions involve critical minerals which have a high environmental impact, their exploitation is not infinite and it is also energy-intensive

The awareness of the human impact on the environment and the global warming is the first step to act sustainable (behaviors skills).

Topics related to renewable energy production and storage, involving the use of critical minerals are not part of the curriculum of science or technology (MIUR, 2012) for this age range (11-14 years-old). In science, phenomenological aspects of energy are emphasized; in technology, where various materials useful to humans are studied, critical minerals or rare earths are not specifically addressed. Then, the adoption of the compulsory Civic (and environmental) Education curriculum allows the various topics related to sustainability to be linked in a transdisciplinary manner. That curriculum also gives to the teacher wide freedom to define appropriate teaching paths even if they are not specifically present in the curriculum, letting students use ICT for information research and artifact making. WV are highly suitable to develop custom pathways a motivating environment that, beyond the topics, improves pupils' digital literacy. The good results obtained in knowledge tests, even for more specific topics, lay the groundwork for implementing educational paths closer to pupils' everyday life, such as the impact of technology on the environment in terms of carbon or water footprint. This also could increase the visibility of geosciences compared to other scientific disciplines.

5. Conclusions

The research activity was planned and developed to support schools in implementing the mandatory civic education curriculum (92/2019 Italian law "The introduction of civic education in the school curriculum") with activities that would be motivating for students and increasing their awareness toward sustainability issues in general, and towards a wise georesource management in particular. This law derives from European guidelines about the competence of the 21th century (Council of the European Union, 2018) which stressed the importance to join knowledge and behavior to be a future decision-maker and change-maker, as the GreenComp indicates. In fact, this framework, developed by the European Commission, focuses specifically on sustainability competences and it provides a common ground for learners and guidance for educators to develop the knowledge, skills, and attitudes necessary to live, work, and act sustainably.

Different platforms were chosen to test any differences from the point of view of pupils' learning and enjoyment, with no substantial differences. This was an important result from our point of view because, beyond the platform used, the particular focus was on content. In fact, in secondary school, the space devoted to geosciences is generally low and even less space/time is devoted to the concept of georesources, particularly energy-critical minerals. The idea to create didactic activities linking together energy, technology, georesources, climate change, urban sustainability and personal lifestyles revealed to be interesting for the students as well as the teachers. The purpose of this research is, in fact, not only to engage the students, as citizens of the future, but also to engage the teachers to involve them in a different way to propose geoscience topics linked to sustainability.

The decision to use virtual worlds as an educational platform was made months before the Covid-19 pandemic, as a way to reach multiple schools simultaneously. During the pandemic, this choice became crucial because distance education was the only way to complete the school year and provided an engaging alternative to video lectures, which were often just digital versions of traditional classroom lectures.

After a general approach to sustainability, we pointed out the attention on the circular economy and waste management of critical raw materials, especially those used in students' everyday life (smartphones and other electronic devices) and in renewable energy equipment. Topics related to critical minerals for energy production and storage are generally not part of a secondary school curriculum, so they generally are not so well-known by K6-K8 students. Since the 2020-2021 school year, the teaching of civic education (Law 92/2019) has been mandatory, allowing teachers considerable freedom in choosing the topics to cover.

However, literature shows few examples of schools engaging in similar activities as RM@Schools, an EU Consortium by EIT Raw Materials (Murphy & Pacher, 2021), which operates in several European countries. These topics have been developed with a focus on carbon footprint measures. In fact, calculating the students' carbon footprint in various activities (A2, A3, A4, A5) has been a way to make them aware of their often-hidden impact, which frequently astonished them.

As indicated in the literature (Annan-Diab & Molinari, 2017), a multidisciplinary approach was implemented in most of the activities, such as in activity A2b (S-City game) and in activities on critical minerals (A3, A4), where, in addition to studying the properties and the environmental impact of their extraction, human rights, labor impacts and social implications were also addressed. Additionally, a brief historical overview of different methods of energy production, both past and present, was included.

5.1 MAIN RESULTS

The following research questions were addressed at the beginning of this research:

- RQ1: Can virtual worlds be effective in acquiring sustainability knowledge by linking geoscience topics interdisciplinary to other topics?
- RQ2: Can virtual worlds help to implement engaging distance learning?
- RQ3: Can virtual worlds be a substrate for the aggregation of different digital and transversal skills?

The main findings of this research globally testify positive answers to these research questions:

- High satisfaction with the activities by teachers, both in those where they were directly involved and in those where they monitored students' activities
- Post-activity knowledge test mean score (for the GBL activities) significantly higher than pre-activity results.
- Higher results in knowledge tests achieved by the student groups that accessed to virtual worlds compared to the control groups (where applicable), both for IBL and GBL activities. It should also be noted that no pre-activity knowledge tests were administered to students in the IBL activities, as the test questions were derived directly from the topics developed by the pupils during the project and could not be predicted beforehand
- In identical activities on different platforms (A3, A4) the equivalent knowledge test results demonstrate how topics are engaging regardless of the platform. This is also the basis for implementing these activities even on easier-to-use web platforms (although less flexible than Opensimulator, which has the disadvantage of requiring high-end PCs and a dedicated server). The impact of 3D objects as interactive mindtools on learning remains to be explored, which is not evidenced by the short time of the GBL experiences (2 hours)
- The analysis of *specific topics* in activity A2a testify students' engagements to energy and critical material related topics, and a general awareness of the role of geosciences
- The analysis of the students' satisfaction survey revealed that the synchronous presence of students in the same virtual environment made them feel closer to their classmates, even when confined at home during a frustrating and unhappy period due to the lack of socialization and physical contact. This is attributed to the affordances of virtual worlds, particularly in fostering communication, collaboration, and interactive work. In open-ended questions, pupils emphasized the motivating aspect of such activities. Students' access to the virtual world highlighted that such activities improve their knowledge, focus, learning, and engagement
- From the analysis of final products and the students' monitoring during work, and also by questionnaires emerge that students improved different digital and transversal skills, using diverse tools and Apps, collaborating at a distance

The positive results demonstrate that specific, even relatively complex topics can be effectively addressed at the secondary school level. The research also shows that active learning, whether game-based or inquiry-based, is consistently effective, as evidenced by the satisfactory outcomes of all activities. Inquiry-based and problem-based learning engaged students in solving real-world problems related to renewable energy (Barry et al., 2017), waste management, and urban sustainability (activities A1, A5, and A6). Game-based learning was efficient for specific topics (Rosmansyah et al.,

2019) such as Agenda 2030 (activities A2a, A2b) and critical minerals (activities A3 and A4). Additionally, interactive objects used as assessment tools within the virtual world activities, along with external links to online forms, provided the scholastic assessment required by teachers after the activities.

Considering that students accessed the virtual world from home for most activities, it highlights their effectiveness in supporting educational sustainability during the Covid-19 period, as well as in normal curricular activities. Even when not used remotely, virtual worlds proved to be environments for cooperation and teamwork (activity A5). They were therefore used as virtual laboratories where students could experiment with ideas and envision their future.

In the IBL activities, taking about ten time more than the GBL activities, observation of students reveals how there were comfortable to act in virtual words. In the creation of final products, the pupils were able to improve their digital skills, from photo and video editing to 3D modeling to storytelling (creation of audio and video narration of the activities performed), all in one hanging environment. They also improved their soft skills especially team work and sharing jobs.

5.2 LIMITATIONS

From the research two main limitations emerge:

a) some virtual worlds platforms require high end PC

b) the teacher mastering of ICT.

The lack of performant PC during the pandemic forced a high number of students to be part of the control group. This issue was in part overcame testing web-based virtual platforms.

The teachers’ digital gap needs more training or, alternatively, it is possible to use virtual platform well-known by students, such as Minecraft. Activity A6 demonstrate that students were totally autonomous in using the platform tools. Teachers have just to assign educational learning objectives and tasks.

5.3 FUTURE WORK

Satisfactory results lay the foundation to propose the use of this platforms at large scale, giving to the teachers clear instructions and protocols to follow, also thinking about more articulated and in-depth thematic paths, useful for older students The goal is to create short but comprehensive learning paths on specific topics as engagement activities to motivate pupils and prepare them for classroom discussion and critical thinking activities. Topics will be designed and planned tacking into account the GreenComp, using the virtual worlds as a role-play of sustainability issues and solutions.

Other 3D web platforms will continue to be tested to identify elements of object interactivity that can make them more appealing and flexible than Opensimulator, overcoming the technical problems.

In addition, future research will focus on testing the use of virtual reality headsets with some of the activities already created to get the most of a technology that only in recent years has begun to be accessible and “mainstream” especially for educational institutions that as of this year can count on generous funds from the PNRR (National Recovery and Resilience Plan). Due to pandemic, also 3D platforms (now generally called *metaverse*) are increasing again in popularity moving a lot of economic interests.

The term *metaverse* appeared for the first time in a novel called Snow Crash by Neal Stephenson (1992) and was intended a parallel virtual word accessed by avatars. This term was also used for Second life and other 3D virtual worlds such as Opensimulator (Dionisio et al., 2013). Now the term indicates a more complex concepts, where people/avatars can move through different types of platforms with different technology with the same digital identity (Ning et al., 2021). The term metaverse became mainstream during Covid-19 pandemic, especially when the virtual mounting headset Oculus Quest 2 was put on the market in October 2020.

Cosio et al. (2023) systematically reviewed papers on virtual and augmented reality for environmental sustainability, covering a span of approximately 15 years. They found 80 papers using virtual reality headset, but approximately only half were empirical, with quantitative/qualitative results with students. Topics were mainly related to botany, climatology, ecosystems. No empirical papers were devoted to geosciences. Among empirical papers focused to sustainability virtual environments were created to change people' behavior about plastic consumption (Chirico et al., 2020).

So, this is a promising area to develop geoscience educational paths, especially related to georesources or field-related activities, also to help students be ready for a future society even more technological than the present one, without disregarding the natural environment and the attentions to its study and preservation. In fact, the activities in different 3D platforms and different learning approaches can be considered an engaging way for students to discover the many interdisciplinary connections between geosciences and sustainability, making them understand the importance of studying the Earth in all aspects, increasing the curiosity and interest towards geoscience topics and highlighting the central role of Geoscientists to meet the Agenda 2030 goals.

Link to the thesis:

https://www.virtualscience.it/publications/PhD_thesis_michelina_occhioni.pdf

michelina.occhioni@unicam.it

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7. Annexes

Annexes are numbered according to the number of the relative chapter.

The first number of the annex is the number of the chapter, the second is the progressive number. For the chapter 3 the number of the chapter is also followed by the number of the research activity.

They contain instructions, questionnaires, detailed results and other supplemental materials.

Annex 2.1. Instructions to access Techland

Hardware requirements

The following requirements should be enough to enter the world, however, sometimes also less performant PC can be suitable. We suggest to try!

From: https://www.craft-world.org/page/en/how-to-start.php

Connection:

Generally a DSL connection with at least 4 Mbit/s in download and 1 Mbit/s in upload may be enough. If the connection is shared with other people (in your family or in your office) then it would be better to consider connections with higher bandwidth.

However, some satellite or wireless connections are not compatible with OpenSim

PC:

Operating system: Windows (8.1 to 11, 64-bit), MacOS (preferably the latest official version), Linux (a modern 32-bit version or a 64-bit version with 32-bit compatibility environment).

RAM: 4GB or more

Video Card: A suitable video card to support 3D games is required (at least an Nvidia GeForce 10 series (1030, 1050, 1060 etc.) or better or AMD Radeon RX 500 series (550, 570, 580 etc.) or better is required for an acceptable experience.

CPU: A modern Intel or AMD processor of at least 2GHz is generally more than enough

Note: Chromebooks are not suitable for Opensimulator

Other references

https://secondlife.com/system-requirements

https://craft-project.eu/wp-content/uploads/2021/11/CRAFT-Platform-manual-final.pdf

Software installation and configuration

This video explains how to:

-Download and configure the viewer Firestorm to access to Sustainability Hub

-Create an avatar

-Access to the island

-Find further instructions in-world

Note: the following video is periodically updated to add details and procedures.

https://www.virtualscience.it/video/techland_international_procedure.mp4

Annex 3.A1.1

Students' pre-activity questionnaire (digital / technical skills)

	Question	Answers
D1	Indicate your knowledge of the following virtual worlds / multimedia tools: • Opensimulator (accessed with the Firestorm viewer) • Minecraft • Online educational games • 3D modeling software (e.g. Tinkercad) • Screen recording programs • Photo editing software • Video editing programs • Platform for remote collaboration (e.g. Microsoft Teams - Google Suite) • Apps to create simple websites • Apps to create multimedia presentations (e.g. Power Point) • Apps for writing documents (e.g. Word)	**Likert scale** 5 = Excellent 4 = Good 3 = Basic 2 = Poor 1 = None
D2	Write the name of some app you usually use to record your PC screen. Write "None" if you don't use any.	Open-ended questions
D3	Write the name of some app you usually use to create videos from different clips. Write "None" if you don't use any.	

Annex 3.A1.2

Students' post-activity questionnaire (Knowledge test)

	Question	Answers
G1	Have you already heard of the topics of the 2030 Agenda for Sustainable Development?	Yes No
	Metal properties	
T1 1pt	Regarding their composition, how metals are commonly classified?	Single-select multiple-choice
	• ferrous and non-ferrous	✓
	• magnetic and non-magnetic	✗
	• native and compound	✗
	• by injection and by molding	✗
T2 1pt	Which of these metals is attracted to magnets?	Single-select multiple-choice
	• Aluminum	✗
	• Iron	✓
	• Gold	✗
	• Zinc	✗
T3 1pt	Which of the two metal melts at the lowest temperature?	Single-select multiple-choice
	• Iron	✗
	• Aluminum	✓
	Recycle process	
T4 3pt	Put the metal recycling phases in order:	Order
	• reduction in metal shavings	4
	• separation between iron and aluminum	3
	• manual separation of small non-metallic materials	2
	• suction of plastic bags	1
	• transport to smelting plants	5
T5 1 pt	How aluminum is generally separated from other waste?	Single-select multiple-choice
	• by a magnet	✗
	• by a chemical process	✗
	• by a system of induced currents	✓
	• by manual sorting	✗
T6 T7 T8	In your opinion, does using recycled metal save energy? Justify your answer. In your opinion, does using recycled metal save energy? Justify your answer. In your opinion, what does it mean to behave in a "sustainable" way?	Open-ended questions

Annex 3.A1.3 - Detail of the open-ended questions

Open ended questions - The importance of recycle.

In your opinion, why is it important to recycle metals?	**Highlights**		
	R	**E**	**P**
Because less raw materials and less energy are consumed, then we avoid polluting the environment.	✓	✓	✓
because less raw materials are used, and energy is saved.	✓	✓	
In my opinion it is important to recycle metals because wasting them is a big mistake because they pollute, and they are not infinite.	✓		✓
To reduce energy consumption, pollution and the advantage they can also be recycled indefinitely.	✓	✓	✓
Because otherwise we would pollute too much, damaging the environment and waste energy.		✓	✓
To reduce the consumption of raw materials, because in this way energy is saved, and to reduce waste in landfills or dispersed in the environment.	✓	✓	✓
For me it is important to recycle metals because they are not created from an infinite material and not to pollute; moreover, energy is saved compared to extracting other minerals.	✓	✓	✓
Producing metals from other metals saves resources and energy.	✓	✓	
%	88%	88%	75%

R = resources saving; E= Energy saving; P = Less pollution

Open ended questions – Energy saving

In your opinion, does using recycled metal save energy? Justify your answer	
Of course, yes, because we avoid producing the metal directly from raw materials.	✓
Yes, it saves energy in the production phases.	✓
In my opinion, yes, because using recycled metal saves the energy needed for the extraction and refining of minerals.	✓
Sure, we save energy for production.	✓
Yes, because by extracting more metal, more energy is wasted.	✓
yes, because to obtain, for example, recycled steel from the raw material, much more energy is needed.	✓
Yes, because metal is a conductor of electricity.	✗
For example, to produce a can from another can, about 90% of energy is saved	✓
88 % of correct answers	

Open ended questions – Sustainable lifestyle

In your opinion, what does it mean to behave in a "sustainable" way?	**Highlights**		
	R	**L**	**P**
It means adopting a lifestyle in favor of our well-being and that of others.		✓	
be more ecological, i.e. separate waste collection, do not abandon waste and respect the environment.	✓	✓	
For me, behaving in a sustainable way means living by recycling what can be recycled and not wasting plastic and various bottles.	✓		
it means taking care of your planet and also taking responsibility for it.		✓	✓
Behaving in a way that does not harm the environment.			✓
Be more aware of the environmental impact and try to do something like recycle.	✓		✓
It means helping the Earth, sorting waste, recycling and not throwing things on the ground.	✓		✓
It means not wasting natural resources.	✓		
%	63%	38%	50%

R = Resources and recycle; L = Lifestyle; P = Planet

Annex 3.A2a.1.

Questions in the 3D interactive quizzes for the badge acquisition at the end of each area

Global issues scenario area

	Questions	Answers
1	**GLOBAL ISSUES**	
	What is the current level of CO2 in the air?	
	320ppm (mg/kg)	✗
	380ppm (mg/kg)	✗
	415ppm (mg/kg)	✓
	How many billion people will there be on Earth in 2050 according to UN estimates?	
	9.8	✓
	8.5	✗
	11.0	✗
	In sub-Saharan Africa live the ___ of all the poor in the world	
	30%	✗
	70%	✗
	50%	✓
	What is Earth Overshoot Day?	
	It is the day of the year in which the most natural resources are used	✗
	It is the day of the year in which humanity has used all the natural resources that the Earth can regenerate in a year.	✓
	It is a specific day of the year dedicated to reflection on the consumption of natural resources	✗
	The UN has raised the risk of extinction for…	
	1 out of 8 million species	✓
	2 out of 8 million species	✗
	0.5 out of 8 million species	✗

Georesources area

	Questions	Answers
2	**GEORESOURCES AND CIRCULAR ECONOMY**	
	WEEE are:	
	Fuel oils	✗
	Waste from electric and electronic equipment	✓
	Nuclear waste	✗
	Which nation consumes the largest quantity of coal in the world?	
	China	✓
	U.S.A.	✗
	India	✗
	Soil loss is mainly caused by:	
	Livestock farm ruining the soil	✗
	Floods	✗
	Overbuilding	✓
	Most abundant element in the earth's crust (after oxygen) used in electronics and other high-tech applications	
	Carbon	✗
	Silicon	✓
	Chlorine	✗
	Which country in the world has the largest reserves of water?	
	United States	✗
	Brazil	✓
	Russia	✗

Environmental footprint indicators area

	Questions	Answers
3	**ENVIRONMENTAL FOOTPRINT INDICATORS**	
	The carbon footprint measures …	
	the number of trees to be planted to compensate for the greenhouse gasses emitted	✗
	the amount of greenhouse gasses emitted	✓
	the amount of coal used for human activities	✗
	The gray component of the water footprint represents water…	
	necessary to dilute the pollutants (for example from industrial processes)	✓
	coming from atmospheric precipitations and stored in the soil	✗
	coming from surface or underground water resources	✗
	The water footprint of a product is the total volume of fresh water used …	
	in the entire production and distribution cycle of that product	✓
	for recycling of that product	✗
	in the collection of raw materials needed to produce that product	✗
	The weight of the "ecological rucksack" of a product ...	
	corresponds to the weight of the product itself	✗
	is less than the weight of the product itself	✗
	sometimes far exceeds the weight of the product itself	✓
	Goal 13 calls for:	
	integrate measures against climate change into all national policies	✓
	strengthen city infrastructures	✗
	achieve gender equality in all Countries	✗

Agenda 2030 and Sustainable Development Goals area

	Questions	Answers
4	**AGENDA 2030 AND SUSTAINABLE DEVELOPMENT GOALS**	
	The first definition of sustainable development…	
	associates the well-being of the present generation with the well-being of future generations	✓
	dates to 2015, with the signing of the 2030 Agenda	✗
	is contained in the Paris Agreement	✗
	The 2030 Agenda includes 169…	
	Targets	✓
	Goals	✗
	Annexes	✗
	Goal 11 calls for:	
	Save energy	✗
	Reduce inequalities	✗
	Built resilient and inclusive cities	✓
	Goal 12 calls for:	
	Increase health and wellbeing	✗
	A more sustainable lifestyle	✓
	Access to clean water	✗
	Goal 13 calls for:	
	integrate measures against climate change into all national policies	✓
	strengthen city infrastructures	✗
	achieve gender equality in all Countries	✗
5	**AIMS OF AGENDA 2030**	
	What is the ultimate goal of the 2030 Agenda?	
	Enrich all the countries of the world	✗
	Make countries collaborate	✗
	Achieve universal peace	✓
	The 2030 Agenda invites all countries to…	
	avoid export of goods	✗
	work together and leave no one behind	✓
	work independently to achieve goals	✗
	The three pillars of sustainability are:	
	environmental, economic, work	✗
	social, economic, environmental	✓
	social, political, economic	✗
	The 5 dimensions of sustainable development are:	
	Planet, People, Peace, Countries, Development	✗
	Environment, Economy, Politics, Resources, Development	✗
	Planet, People, Partnership, Peace, Prosperity	✓
	The achievement of each Goal of the 2030 Agenda is:	
	independent of each other	✗
	closely related and dependent on each other	✓
	partially dependent on each other	✗

Annex 3.A2a.2.

Phase 1 survey. Teachers' satisfaction questionnaire

n.	Questions	Answers
	GENERAL TEACHERS' INFORMATION	
1	Gender	● Male ● Female ● Prefer not to say
2	Age	● Less than 30 ● 30-39 ● 40-49 ● 50-59 ● 60 and more ● Prefer not to say
3	Educational stage	● Primary School ● Lower Secondary School ● Higher Secondary School
4	Teaching subject	● Italian History, Geography ● Mathematics, Science ● Physics, Chemistry ● Technology ● Art ● Computer Science, ● Foreign Languages ● Other (specify)
5	Number of years of service as teacher	● Less than 5 ● 6-10 ● 11-15 ● 16-20 ● 21-25 ● 26-30 ● more than 30
6	Have you already dealt in class with the themes of the Agenda 2030 and Sustainable Development	● Yes ● No
7	List the main topics covered by you in the Environmental Education curriculum (more than one possible answer). ● Energy and domestic consumption ● Food Sustainability - km 0 supply chain ● Circular Economy ● Waste Management ● Transportation ● Greenhouse effect and climate change ● Environmental Footprint Indicators (water footprint, carbon footprint, and ecological rucksack) ● Conscious consumption ● Biodiversity ● The social / economic aspects of Sustainability ● Natural resources and their exploitation ● None of these topics are covered ● Other (specify)	Multi-select multiple-choice

<table>
<tr><th>n.</th><th>Questions

TEACHERS’ SATISFATION</th><th>Answers</th></tr>
<tr><td>8</td><td>For which grade level of school are the topics at Sustainability Hub suitable? (select one or more choices)</td><td>● Primary School
● Lower Secondary School
● Higher Secondary School (K9-K10 grade)
Higher Secondary School (K11-K12 grade)</td></tr>
<tr><td>9</td><td>Rate your level of agreement with each statement
● The learning scenario is engaging
● The educational pathway is consistent with the sustainability topics
● Web resources are suitable for learning
● The multimedia presentations and info-panels are clear and self-explanatory
● On-line games are suitable for learning
● The number of practical activities is enough to foster learning
● Practical activities are well-structured
● Moving through the different part of the island is easy
● I've experienced difficulties with the viewer firestorm (reverse scored)
● Learning path are clearly highlighted (37 teachers)</td><td>Likert scale
1 - Strongly disagree
2 - Disagree
3 - Neither agree or disagree
4 - Agree
5 - Strongly agree</td></tr>
<tr><td>10</td><td>Rate your level of satisfaction about the quality of educational objects in Sustainability Hub?
● Multimedia presentations
● Links to external resources
● Quizzes to acquire badges
● Interactive charts
● The SDGs path
● The game of the 4Rs
● The TRUE/FALSE cubes (the blue cubes clicked to answers questions in various sections)
● 3D interactive objects
● The graphics and colors of the island
● The online games
● The temple of Sustainability
● The Guillotine Game
● The Footprint Calculator
● The Waterwall
● The Wheel of Goals
● The Sustainability City Game</td><td>Likert Scale
0 - No time to test it
1 - Very dissatisfied
2 - Dissatisfied,
3 - Neither satisfied nor dissatisfied
4 - Satisfied
5 - Very satisfied</td></tr>
<tr><td>11</td><td>From a technical point of view in using the viewer Firestorm, did you experience difficulties with the following aspects?
● Internet connection
● PC characteristics not suitable for Firestorm
● Communication (chat and voice)
● The movement of the avatar (walking and flying)
● The use of the cam for close-up views
● The interaction with objects
● Inventory management
● Change the appearance of the avatar
● Taking pictures
● Uploading photos in the world
● The teleportation system</td><td>Likert Scale
1 - Extremely
2 - Very
3 - Moderately
4 - Slightly
5 - Not at all</td></tr>
<tr><td>12</td><td>Suggestions for future new topics/sections of the island</td><td>Open ended questions</td></tr>
<tr><td>13</td><td>Suggestions to improve the educational path of the island</td><td>Open ended questions</td></tr>
</table>

Annex 3.A2a.3.

Phases 2 and 3 survey - Students' pre-activity questionnaire

n.	GENERAL QUESTIONS	Answers
G1	Gender	Male Female Prefer not to say
G2	Name of the school	open ended question
G3	Educational stage	Lower Sec. School Higher Sec. School
G4	Grade	K6,...., K12
G5	Section	A,...Z
C1	Have you already dealt in class with the themes of the Agenda 2030 and Sustainable Development	Yes No
C2	Through which information channels did you hear about the Agenda 2030? ● Internet ● TV ● Newspaper and magazines ● School ● Talking with family and friends ● Other (specify)...	Multiple-select multiple-choice
C3	In which teaching class did you hear about the Agenda 2030? ● Humanistic subjects ● Scientific subjects ● Art ● Environmental Education ● Specific projects ● None ● Other (specify)...	Multiple-select multiple-choice

	KNOWLEDGE TEST	**Answers**
T1	In your opinion, what is the most complete definition of Sustainable Development?	Single-select multiple-choice
	● Increase in wealth and well-being	✗
	● Development that meets all our needs	✗
	● Development that meets our needs and those of future generations	✓
	● Environmental protection	✗
T2	To act sustainably, in which order these actions should be taken?	
T3	● Repair	Reduce
	● Recycle	…
	● Reduce	…
	● Reuse	Recycle
T4	Soil is renewable because it regenerates easily thanks to rock erosion	True/False F
	Select all correct statements about fossil fuels:	Multiple-select multiple-choice
T5	● Fossil fuels are used for heating and energy production	✓
T6	● Fossil fuels are responsible for global warming	✓
T7	● Fossil fuels are responsible for the ozone hole	✗
T8	● Fossil fuels produce greenhouse gasses	✓
T9	● Fossil fuels are renewable	✗
T10	Over the past 50 years, the amount of CO_2 in the air has remained more or less the same	True/False F
T11	The global average temperature has increased by more than 2°C in the last 50 years	True/False F
T12	The Water footprint refer to:	Single-select multiple-choice
	● Soil washout due to heavy rains	✗
	● Consumption of water necessary to produce objects or food or services	✓
	● Running water consumption	✗
	● The amount of rainwater that falls in a year	✗
T13	The Carbon Footprint of a product or service (e.g. public transportation) measures …	Single-select multiple-choice
	● the amount of natural resources needed to produce that product or service	✗
	● the amount of coal required to produce that product or service	✗
	● the amount of greenhouse gasses emitted, especially carbon dioxide, to produce that product or service	✓
	● the amount of trees needed to absorb the carbon dioxide emitted to produce that product/service	✗
T14	The Ecological Rucksack refer to:	Single-select multiple-choice
	● A rucksack made with eco-sustainable materials	✗
	● the amount of natural resources needed to produce that product or service	✓
	● the amount of greenhouse gasses emitted, especially carbon dioxide, to produce that product or service	✗
	● the guarantee that no child labor has been used to produce a given good or service	✗

ST	SPECIFIC TOPICS	Answers
ST2	**Deepening on Environmental Footprint Indicators**	
ST2a	The Ecological Footprint is related to …	Single-select multiple-choice
	● the surface area used to produce goods and to dispose of the waste produced	✓
	● The water used to produce goods and to dispose of the waste produced	✗
	● the resources used to produce goods and to dispose of the waste produced	✗
	● The labor used to produce goods and to dispose of the waste produced	✗
ST2b	Indicates the approximate value of the water footprint of a typical breakfast with milk and cereals	Single-select multiple-choice
	● Less than 1 liter	✗
	● 3 liters	✗
	● 30 liters	✗
	● 300 liters	✓
P	**PERCEPTION OF GLOBAL ENVIRONMENTAL ISSUES AND CONCEPT OF RESOURCE/WASTE**	**Answers**
P1	In your opinion, what are the most pressing environmental problems that should be solved with the highest priority (more than one answer allowed: ● Shortage of drinking water ● Global warming ● Demographic growth ● Overexploitation of natural resources ● Loss of biodiversity	Multiple-select multiple-choice
P2	In your opinion, which of the following are resources? ● Water ● Waste to be differentiated ● An old PC / a broken mobile phone ● Food waste ● Wind ● Internal heat of the Earth ● Car exhaust fumes ● Soil	Multiple-select multiple-choice
D	**DIGITAL SKILLS**	
D1	How would you describe your level of expertise in… ● 3D modeling ● Video making ● Image editing ● multimedia presentation ● coding (e.g. scratch) ● Virtual tour (e.g. Thinglink, Google Earth)	**Likert scale** 1- No knowledge 2- Little knowledge, the basic functions 3- I juggle easily 4- I get good results 5- I'm a real champion!
D2	How would you describe your knowledge in the following virtual world? ● Minecraft ● Mozilla Hub / other web-based virtual worlds ● Opensimulator ● Cospaces ● Artsteps	**Likert scale** 1- Never heard of it 2- Heard of it, but never used it 3- I use it little 4- I use it often 5-I always use it

Annex 3.A2a.4.

Phases 2 and 3 survey - Students' post-activity questionnaire

n.	General questions	Answers
G1	Gender	Male Female Prefer not to say
G2	Name of the school	open ended question
G3	Educational stage ● Lower secondary school ● Higher secondary school	Single-select multiple-choice
G4	Grade	K6, …, K12
G5	Section	A,...Z
G6	Did you access Sustainability Hub with your personal avatar?	Yes No
	KNOWLEDGE TEST	
T1	In your opinion, what is the most complete definition of Sustainable Development?	Single-select multiple-choice
	● Increase in wealth and well-being	✗
	● Development that meets all our needs	✗
	● Development that meets our needs and those of future generations	✓
	● Environmental protection	✗
T2	To act sustainably, which of these actions of the so-called 4R would you take first?	Single-select multiple-choice
	● Repair	✗
	● Recycle	✗
	● Reduce	✓
	● Reuse	✗
T3	To act sustainably, which of these actions of the so-called 4R would you take after all others?	Single-select multiple-choice
	● Repair	✗
	● Recycle	✓
	● Reduce	✗
	● Reuse	✗
T4	Can soil be considered easily renewable?	Single-select multiple-choice
	● YES, because it regenerates through the erosion of the rocks	✗
	● NO, because it takes thousands of years to regenerate	✓
	Select all correct statements about fossil fuels:	Multiple-select multiple-choice
T5	● Fossil fuels are used for heating and energy production	✓
T6	● Fossil fuels are responsible for global warming	✓
T7	● Fossil fuels are responsible for the ozone hole	✗
T8	● Fossil fuels do not produce greenhouse gasses	✗
T9	● Fossil fuels are not renewable	✓

T10	What is the current average level of carbon dioxide in the air?	Single-select multiple-choice
	● about 250 ppm (mg/Kg)	✗
	● about 410 ppm (mg/Kg)	✓
	● about 320 ppm (mg/Kg)	✗
	● about 280 ppm (mg/Kg)	✗
T11	The average global temperature increase, compared to the pre-industrial era, is about …	Single-select multiple-choice
	● 0°C	✗
	● 1°C	✓
	● 1.5°C	✗
	● 2°C	✗
T12	The Water Footprint refers to:	Single-select multiple-choice
	● Soil washout due to heavy rains	✗
	● Consumption of water necessary to produce objects or food or services	✓
	● Running water consumption	✗
	● The amount of rainwater that falls in a year	✗
T13	The Carbon Footprint of a product or service measures …	Single-select multiple-choice
	● the amount of natural resources needed to produce that product or service	✗
	● the amount of coal required to produce that product or service	✗
	● the amount of greenhouse gasses emitted, especially carbon dioxide, to produce that product or service	✓
	● the amount of trees needed to absorb the carbon dioxide emitted to produce that product/service	✗
T14	The Ecological Rucksack refers to:	Single-select multiple-choice
	● A rucksack made with eco-sustainable materials	✗
	● The amount of natural resources needed to produce that product or service	✓
	● The amount of greenhouse gasses emitted, especially carbon dioxide, to produce that product or service	✗
	● The guarantee that no child labor has been used to produce a given good or service	✗
ST	**SPECIFIC TOPICS**	
ST1	**Agenda 2030**	
ST1a	The Agenda 2030 SDGs are …	True/False
	● interconnected and interdependent	T
	● divided into 169 targets	T
	● aimed at achieving universal peace	T
	● included in a program that concerns people, the planet, governance and, economic development	T
	● shared only by some UN member countries	F
ST1b	The "pillars" on which sustainability is based, according to what is highlighted by the Agenda 2030 SDGs, are:	Single-select multiple-choice
	● economic, social, political	✗
	● social and environmental	✗
	● environmental and economic	✗
	● environmental, economic, social	✓

ST2	**Deepening on Environmental Footprint Indicators**	
ST2a	The Ecological Footprint is related to …	Single-select multiple-choice
	● The surface area used to produce goods and to dispose of the waste produced	✓
	● The water used to produce goods and to dispose of the waste produced	✗
	● The resources used to produce goods and to dispose of the waste produced	✗
	● The labor used to produce goods and to dispose of the waste produced	✗
ST2b	Indicate the approximate value of the water footprint of a typical breakfast with milk and cereals	Single-select multiple-choice
	● Less than 1 liter	✗
	● 3 liters	✗
	● 30 liters	✗
	● 300 liters	✓
P	**PERCEPTION OF GLOBAL ENVIRONMENTAL ISSUES AND CONCEPT OF RESOURCE/WASTE**	
P1	In your opinion, what are the most pressing environmental problems that should be solved with the highest priority (more than one answer allowed: ● Shortage of drinking water ● Global warming ● Demographic growth ● Overexploitation of natural resources ● Loss of biodiversity	Multiple-select multiple-choice
P2	In your opinion, which of the following can be considered resources? ● Water ● Waste to be differentiated ● An old PC / a broken mobile phone ● Food waste ● Wind ● Internal heat of the Earth ● Car exhaust fumes ● Soil	Multiple-select multiple-choice
W	**STUDENTS' POINTS OF VIEW**	
W1	Rate your level of agreement with each statement ● The Earth's population is increasing rapidly but this is not a problem because resources are sufficient for all ● It is not necessary to reduce consumption and simplify lifestyles. Resources are enough for all ● The contribution of a single person is minimal towards the importance of environmental issues. Any personal effort is useless	**Likert scale** 5 - Strongly disagree 4 - Disagree 3 - Neither agree or disagree 2 - Agree 1 - Strongly agree
W2	What is, in your opinion, the meaning of "acting in a sustainable way?"	Open-ended question
W3	Indicate 3 practical actions you are ready to carry out immediately to modify your lifestyle towards sustainability	Open-ended question
W4	Indicate which characteristics, in your opinion, an ideal sustainable city should have	Open-ended question
W5	Indicate which actions are effective to save energy or limit the emission of greenhouse gasses	Open-ended question

S	**SATISFACTION SURVEY**	
S1	Rate your level of agreement with each statement **Quality of the learning scenario** ● The educational path is well organized and structured ● The scenario is pleasant (graphics and colors) ● Information in the island is clear and explicative ● The 3D learning objects and graph helped me to understand concepts and data **Learning experience** ● This activity increases my learning focus ● This activity increased my knowledge ● This activity gave me engagement and enjoyment	**Likert scale** 1 - Strongly disagree 2 - Disagree 3 - Neither agree or disagree 4 - Agree 5 - Strongly agree
S2	Rate your level of satisfaction about the quality of educational objects in Sustainability Hub? ● Multimedia presentations ● Links to external resources ● Quizzes to acquire badges ● Interactive charts ● The SDGs path ● The game of the 4Rs ● The TRUE/FALSE cubes (the blue cubes clicked to answers questions in various sections) ● 3D interactive objects ● The graphics and colors of the island ● The online games ● The temple of Sustainability ● The Guillotine Game ● The Footprint Calculator ● The Waterwall ● The Wheel of Goals ● The Sustainability City Game	**Likert Scale** 0 - No time to test it 1 - Very dissatisfied 2 - Dissatisfied, 3 - Neither satisfied nor dissatisfied 4 - Satisfied 5 - Very satisfied
S3	**Ease of use** From a technical point of view regarding the use of the viewer Firestorm, did you experience difficulties with the following aspects? ● Internet connection ● PC characteristics not suitable for Firestorm ● Communication (chat and voice) ● The movement of the avatar (walking and flying) ● The use of the cam for close-up views ● The interaction with objects ● Inventory management ● Change the appearance of the avatar ● Take pictures ● Upload photos in the world ● The teleportation system	Likert Scale 1 - Always 2 - Often 3 - Sometimes 4 - Rarely 5 - Never
S4	Suggestions for future new topics/sections of the island	Open ended questions
S5	Suggestions to improve the educational path of the island	Open ended questions

Annex 3.A3.1.

A3 activity - Students' pre-activity questionnaire

n.	STUDENTS' INFO	Answers
G1	Gender	Male Female Prefer not to say
G2	Name of the school	open ended question
G3	Educational stage	Lower Sec. School Higher Sec. School
G4	Grade	K6, ..., K12
G5	Section	A, ..., Z
G6	Students' code (ask your teacher)	open ended question
D	**STUDENTS' DIGITAL SKILLS**	
D1	How would you describe your level of expertise in…? ● 3D modeling ● Video making ● Image editing ● multimedia presentation ● coding (e.g. Scratch) ● Virtual tour (e.g. Thinglink, Google Earth)	Likert scale 1- No knowledge 2- Little knowledge, the basic functions 3- I juggle easily 4- I get good results 5- I'm a real champion!
D2	How would you describe your knowledge in the following virtual world? ● Minecraft ● Mozilla Hub / other web-based virtual worlds ● Opensimulator ● Cospaces ● Artsteps ● FrameVR ● Spatial	Likert scale 1- Never heard of it 2- Heard of it, but never used it 3- I use it little 4- I use it often 5-I always use it

T	KNOWLEDGE TEST	Answers
T1	In your opinion, what is the most complete definition of Sustainable Development?	Single-select multiple-choice
	● Increase in wealth and well-being	✗
	● Development that meets all our needs	✗
	● Development that meets our needs and those of future generations	✓
	● Environmental protection	✗
	Assign the following energy sources to the "Renewable" and "Non-Renewable" groups:	Multiple-choice grid R = Renewable; NR = Non-renewable
T2	● Dams, sea water	R
T3	● Coal	NR
T4	● Sun	R
T5	● Methane and other gases, such as LPG (liquefied petroleum gas)	NR
T6	● Air	R
T7	● Petroleum derivatives	NR
T8	● Wood and other biofuel, such as ethanol from food waste	R
T9	● Hydrogen	R
	For each of the following statements, indicate whether they are TRUE or FALSE	True / false
T10	● Electric power is measured in Joule (J)	F
T11	● The electrical power of an appliance indicates the energy required by an appliance to operate	F
T12	● If electricity is produced from wind energy, no carbon dioxide is emitted (also considering the construction of wind turbines)	F
T13	● The carbon footprint measures the amount of carbon required to produce an item or service	F
T14	● Fossil fuels are not renewable	V
T15	● Fossil fuels do not produce greenhouse gases	F
T16	● Fossil fuels are indirectly responsible for melting glaciers	V
T17	● The combustion reaction produces carbon dioxide	V
T18	● Compared to the pre-industrial era, the average temperature of the Earth has increased by about 2°C	F
T19	● the carbon dioxide in the air dissolves in the waters of the seas and oceans and makes them less acidic	F
T20	● WEEE means environmental risk from electricity and electromagnetism	F
T21	● There is less gold in 1 ton of electronic waste than 1 ton of gold-mining rock	F
T22	● Cobalt and lithium are key components of smartphone batteries	V
T23	● Coltan is a mineral used in the construction industry.	F
T24	● Mining minerals for electronic devices is a low-cost process with little environmental impact	F
T25	● The component of photovoltaic panels that transforms light into electricity is silicon	V

Annex 3.A3.2

List of the online games

n. GAME	LINK	SECTION
A1	https://learningapps.org/watch?v=pj7wh3kwc22	Fossil fuel and climate change
A2	https://learningapps.org/watch?v=p53b2oqu222	Production of renewable energy
A3	https://learningapps.org/watch?v=ph5mi3fxj22	Production of renewable energy
A4	https://learningapps.org/watch?v=p56rpfshj22	Carbon footprint of energy production
A5	https://learningapps.org/watch?v=p3qkzs85t22	Carbon footprint of energy production
A6	https://learningapps.org/watch?v=pnqw9pex522	Critical minerals for technology and energy transition (and WEEE)
A7	https://learningapps.org/watch?v=pth82r4gc22	Critical minerals for technology and energy transition (and WEEE)
A8	https://learningapps.org/watch?v=p73ks8mck22	Critical minerals for technology and energy transition (and WEEE)
A9	https://learningapps.org/watch?v=p1opqraoj22	Critical minerals for technology and energy transition (and WEEE)

Annex 3.A3.3

A3 activity - Students' post-activity questionnaire

n.	**STUDENTS' INFO**	**Answers**
G1	Gender	Male Female Prefer not to say
G2	Name of the school	open ended question
G3	Educational stage ● Lower secondary school ● Higher secondary school	Single-select multiple-choice
G4	Grade	K6, …, K12
G5	Section	A,...Z
G6	Students' code (ask your teacher)	open ended question
T	**KNOWLEDGE TEST**	
T1	In your opinion, what is the most complete definition of Sustainable Development?	Single-select multiple-choice
	● Increase in wealth and well-being	✗
	● Development that meets all our needs	✗
	● Development that meets our needs and those of future generations	✓
	● Environmental protection	✗
T2	What of these pictures display the Sustainable Development Goal "Ensure access to affordable, reliable, sustainable and modern energy for all"?  A B C D	Single-select multiple-choice
	● A	✗
	● B	✓
	● C	✗
	● D	✗
	Assign the following energy sources to the "Renewable" and "Non-Renewable" groups:	Multiple-choice grid R = Renewable; NR = Non-renewable
T3	● Dams, sea water	R
T4	● Coal	NR
T5	● Sun	R
T6	● Methane and other gases, such as LPG (liquefied petroleum gas)	NR
T7	● Air	R
T8	● Petroleum derivatives	NR
T9	● Wood and other biofuel, such as ethanol from food waste	R
T10	● Hydrogen	R

	Select all correct statements about fossil fuels:	Multiple-select multiple-choice
T11	● Fossil fuels are renewable	✗
T12	● Fossil fuels are indirectly responsible for melting glaciers	✓
T13	● Fossil fuels do not produce greenhouse gasses	✗
T14	Which of these reactions is NOT a combustion? **A** $C + O_2 \longrightarrow CO_2$ **B** $S + O_2 \longrightarrow SO_2$ **C** $Fe + 3O_2 \longrightarrow 3\,Fe_2O_3$ **D** $CH_4 + O_2 \longrightarrow CO_2 + 2\,H_2O$	Single-select multiple-choice
	● A	✗
	● B	✗
	● C	✓
	● D	✗
T15	The average global temperature increase, compared to the pre-industrial era, is about …	Single-select multiple-choice
	● 0°C	✗
	● 1°C	✓
	● 1.5 °C	✗
	● 2°C	✗
T16	Carbon dioxide dissolves in the seas and oceans water and makes them…	Single-select multiple-choice
	● More acidic	✓
	● Less acidic	✗
	● More turbid	✗
	● Less rich in oxygen	✗
T17	In a photovoltaic panel, what is the fundamental metal that captures the sunlight?	Single-select multiple-choice
	● Silicon	✓
	● Aluminum	✗
	● Lithium	✗
	● Cobalt	✗
T18	In the ranking of the regions with the largest installed capacity of wind turbines, which is in first place?	Single-select multiple-choice
	● Sardinia, with about 25% of all Italian production	✗
	● Puglia, with about 25% of all Italian production	✓
	● Sicily, with about 25% of all Italian production	✗
	● Lombardy, with about 25% of all Italian production	✗
T19	Which is the Apulian province with the highest installed capacity of wind farms?	Single-select multiple-choice
	● Foggia	✓
	● Bari	✗
	● BAT	✗
	● Brindisi	✗
	● Lecce	✗
	● Taranto	✗

T20	The Carbon Footprint of a product or service (e.g. public transportation) measures …	Single-select multiple-choice
	● the amount of natural resources needed to produce that product or service	✗
	● the amount of coal required to produce that product or service	✗
	● the amount of greenhouse gasses emitted, especially carbon dioxide, to produce that product or service	✓
	● the amount of trees needed to absorb the carbon dioxide emitted to produce that product /service	✗
T21	When electricity is consumed, is the emission of carbon dioxide always equal to zero?	Single-select multiple-choice
	● Yes, always, because there is no combustion	✗
	● Yes, but only if the electricity is produced from renewable sources (e.g. solar or wind)	✗
	● NO, because even if electricity is produced from renewable sources, fossil fuels are almost always used to produce the materials needed to build solar and wind farms	✓
	● NO, because electricity is obtained only from fossil fuels	✗
T22	The electrical power of a household appliance is...	Single-select multiple-choice
	● The work done (and therefore the energy consumed), for example, by a household appliance	✗
	● The work performed (and therefore the energy consumed) in the unit of time, for example, by a household appliance	✓
T23	Electrical power is measured in...	Single-select multiple-choice
	● W (Watt) or KW	✓
	● J (Joule)	✗
	● kWh (kilowatt hours)	✗
	● N (Newton)	✗
T24	One of these items is not recovered from Waste Electrical and Electronic Equipment (WEEE)	Single-select multiple-choice
	● Gold	✗
	● Silver	✗
	● Copper	✗
	● Phosphorus	✓
T25	One of the components of "Coltan" (Tantalum) is used	Single-select multiple-choice
	● in the electronic device industry (makes screen colors brighter)	✓
	● in the construction industry (makes concrete harder)	✗
	● in the electronic device industry (stores a lot of electric charge)	✗
	● in the ceramics industry (makes them whiter)	✗
	Select all the right answers:	Multiple-select multiple-choice
T26	● The extraction of minerals used for electronic devices and the production of renewable energy has a low environmental impact	✗
T27	● Cobalt and lithium are key components of smartphone batteries	✓
T28	● WEEE stands for Waste Electrical and Electronic Equipment	✓
T29	● 1 ton of WEEE contains less gold than 1 ton of rock from which it is mined.	✗
T30	● Neodymium has strong magnetic properties	✓
T31	● Rare earth elements separate easily because they have very different properties	✗
T32	● WEEE are divided into 4 categories	✓
T33	● More than 50% of wrecked cars batteries are recycled worldwide	✗

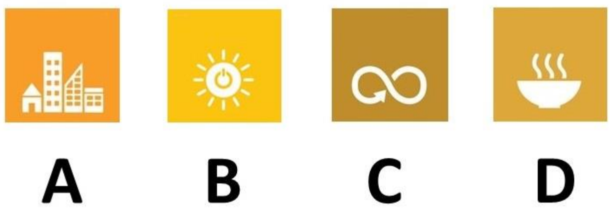
	Select all the right answers:	Multiple-select multiple-choice
T34	● The largest reserves of Coltan are in Brazil	✗
T35	● The Bayan Obo mine is located in China	✓
T36	● Europe is rich in minerals suitable for technology	✗
T37	● Europe's plan to reduce its carbon footprint is called the Green Deal	✓
V	**STUDENTS' POINT OF VIEW**	
V1	Write 3 key messages that stick with you from the topics covered in Powerland	Open-ended question
V2	What is, in your opinion, the meaning of "acting in a sustainable way?"	Open-ended question
V3	Indicate 3 practical actions you are ready to carry out immediately to modify your lifestyle towards sustainability	Open-ended question
S	**STUDENTS' SATISFACTION SURVEY**	
S1	Rate your level of agreement with each statement **Quality of the learning scenario** ● The educational path is well organized and structured ● The scenario is pleasant (graphics and colors) ● Time was enough to accomplish the mission ● There are not enough hands-on activities to do (RS) ● The multimedia presentations and info-panels are clear and explanatory ● Information in the island is clear and explanatory ● On-line games are suitable for learning ● Different sections of the scenario were clearly labeled **Learning experience** ● This activity increased my learning focus ● This activity increased my knowledge ● This activity gave me engagement and enjoyment ● I felt comfortable doing hands-on activities in a virtual world ● Performing a mission motivated me within the virtual world ● I would use this virtual world to collaborate remotely with my classmates ● It was helpful to have the groups work on separate areas ● I prefer the classroom lesson with respect to one in a virtual world (RS)	**Likert scale** 1 - Strongly disagree 2 - Disagree 3 - Neither agree or disagree 4 - Agree 5 - Strongly agree Questions labeled with RS are reverse scored
S2	**From a technical point of view regarding the use of the platform, did you experience difficulties with the following aspects?** ● Internet connection ● PC requirements ● Customizing my avatar ● Movement of the avatar ● Communication with other avatars ● Opening online games ● Browsing multimedia presentation	**Likert Scale** 1 - Extremely 2 - Very 3 – Moderately 4 – Slightly 5 = Not at all.
S3	Suggestions to improve the educational path of the island	Open ended questions
S4	In your opinion, there are advantages/disadvantages of using a virtual world for distance learning?	Open ended questions

Questions T2, T18, T19, T24, T30, T31, T32, T33, T34, T35, T36, T37 were not used to compare results with the mean test score of the pre-activity.

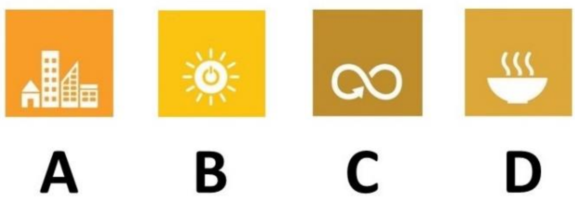
Annex 3.A5. 1

A5 activity - Students' post-activity questionnaire

n.	**STUDENTS' INFO**	**Answers**
G1	Gender	Male Female Prefer not to say
G2	Name of the school	open ended question
G3	Educational stage ● Lower secondary school ● Higher secondary school	Single-select multiple-choice
G4	Grade	K6, …, K12
G5	Section	A,...Z
G6	Students' code (ask your teacher)	open ended question
T	**KNOWLEDGE TEST**	
T1	In your opinion, what is the most complete definition of Sustainable Development?	Single-select multiple-choice
	● Increase in wealth and well-being	✗
	● Development that meets all our needs	✗
	● Development that meets our needs and those of future generations	✓
	● Environmental protection	✗
T2	What of these pictures display the Sustainable Development Goal "Ensure access to affordable, reliable, sustainable and modern energy for all"?	Single-select multiple-choice



	● A	✗
	● B	✓
	● C	✗
	● D	✗
T3	What of these pictures display the Sustainable Development Goal "Ensure access to affordable, reliable, sustainable and modern energy for all"?	Single-select multiple-choice



	● A	✗
	● B	✗
	● C	✓
	● D	✗

	Assign the following energy sources to the "Renewable" and "Non-Renewable" groups:	Multiple-choice grid R = Renewable; NR = Non-renewable
T4	● Dams, sea water	R
T5	● Coal	NR
T6	● Sun	R
T7	● Methane and other gases, such as LPG (liquefied petroleum gas)	NR
T8	● Air	R
T9	● Petroleum derivatives	NR
T10	● Wood and other biofuel, such as ethanol from food waste	R
T11	● Hydrogen	R
T12	The electrical power of a household appliance is...	Single-select multiple-choice
	● The work done (and therefore the energy consumed), for example, by a household appliance	✗
	● The work performed (and therefore the energy consumed) in the unit of time, for example, by a household appliance	✓
T13	Electrical power is measured in...	Single-select multiple-choice
	● W (Watt) or KW	✓
	● J (Joule)	✗
	● kWh (kilowatt hours)	✗
	● N (Newton)	✗
T14	The average percentage of energy required for transportation is about __________ of total energy	Single-select multiple-choice
	● 10%	✗
	● 20%	✗
	● 30%	✓
	● 40%	✗
T15	Horizontal wind turbines work well with little wind or wind of variable direction.	True or False
	T	
	F	T
T16	In a photovoltaic panel, what is the fundamental metal that captures the sunlight?	Single-select multiple-choice
	● Silicon	✓
	● Aluminum	✗
	● Lithium	✗
	● Cobalt	✗
T17	Wind and solar power plants produce electricity …	Single-select multiple-choice
	● discontinuously	✓
	● continuously	✗
T18	• Solar-powered electric car charging stations are typically placed:	✗
	• in very sunny places	✓
	• In places where there is no direct access to electricity	✗
	• In places where electricity is very expensive	✗
	• in any place because they are cheap	

T19	The Carbon Footprint of a product or service (e.g. public transportation) measures … ● the amount of natural resources needed to produce that product or service ● the amount of coal required to produce that product or service ● the amount of greenhouse gasses emitted, especially carbon dioxide, to produce that product or service ● the amount of trees needed to absorb the carbon dioxide emitted to produce that product /service	Single-select multiple-choice ✗ ✗ ✓ ✗
T20	When electricity is consumed, is the emission of carbon dioxide always equal to zero? ● Yes, always, because there is no combustion ● Yes, but only if the electricity is produced from renewable sources (e.g. solar or wind) ● NO, because even if electricity is produced from renewable sources, fossil fuels are almost always used to produce the materials needed to build solar and wind farms ● NO, because electricity is obtained only from fossil fuels	Single-select multiple-choice ✗ ✗ ✓ ✗
T21	During the entire life cycle of a mobile phone, about _______ of carbon dioxide is emitted ● 8 Kg ● 80 Kg ● 800 Kg ● 8000 Kg	Single-select multiple-choice ✗ ✓ ✗ ✗
T22	Exchanging data from the Internet requires energy, so it produces emissions. Which Apps transfer the most data (in terms of Gbytes) for the same amount of time? ● E-mail ● Streaming apps ● Social media ● Music apps	Single-select multiple-choice ✗ ✓ ✗ ✗
T23	Which of these two actions decreases the carbon footprint of a mobile phone the most? ● Making it last longer ● Use it less	Single-select multiple-choice ✓ ✗
T24	The manufacturing of a smartphone accounts for about _____of CO2 emissions its entire life cycle ● 20% ● 40% ● 60% ● 80%	Single-select multiple-choice ✗ ✗ ✗ ✓
T25	What is the amount of rare earths contained in a mobile phone? ● less than 1 % of the total weight ● 5 percent of the total weight approximately ● About 10% of the total weight approx. ● 20% of the total weight approximately	Single-select multiple-choice ✓ ✗ ✗ ✗
T26	The basic components of a mobile phone battery that enable it to store charge are.... ● Lithium and Cobalt ● Aluminum and Copper ● Silicon and Gold ● Iron and Phosphorus	Single-select multiple-choice ✓ ✗ ✗ ✗

T27	They serve to make the colors of a mobile phone screen vivid	Single-select multiple-choice
	• Lithium and Cobalt	✗
	• Rare Earths Elements	✓
	• Tantalum and Indium	✗
	• Silicon and Gold	✗
T28	It has excellent thermal and electrical conductivity and is used in microelectronic components in PCs and mobile phones.	Single-select multiple-choice
	• Lithium	✗
	• Cobalt	✗
	• Gold	✓
	• Silicon	✗
	Select all the right answers:	Multiple-select multiple-choice
T29	• Cities consume about 70 percent of all the world's energy	✓
T30	• The percentage of energy consumed in buildings compared to total energy (construction, electricity, heating) is about 20%	✗
T31	• photovoltaic panels can be directly connected to electric car charger	✗
T32	• Parking lots with photovoltaic panels increase land consumption	✓
T33	• solar panels are not suitable in circuits to heat water	✓
T34	• A mature tree on average absorbs about 22 kg of CO_2 per year	✓
T35	• China has a monopoly on rare earths and minerals for technology in general	✓
T36	• WEEE means environmental risk from electricity and electromagnetism (RAEE significa rischio ambientale da elettricità ed elettromagnetismo)	✗

Questions will be grouped in the following themes

Sustainability and Agenda 2030: Questions T1, T2, T3
Renewable energy: Questions T4, T5, T6, T7, T8, T9, T10, T11
Energy consumption: Questions T12, T13, T14, T29, T30
Equipment for energy transition: Questions T15, T16, T17, T18, T31, T32, T33
Carbon Footprint: Questions T19, T20, T21, T22, T23, T24, T34
Critical minerals: Questions T25, T26, T27, T28, T29, T30, T35, T36

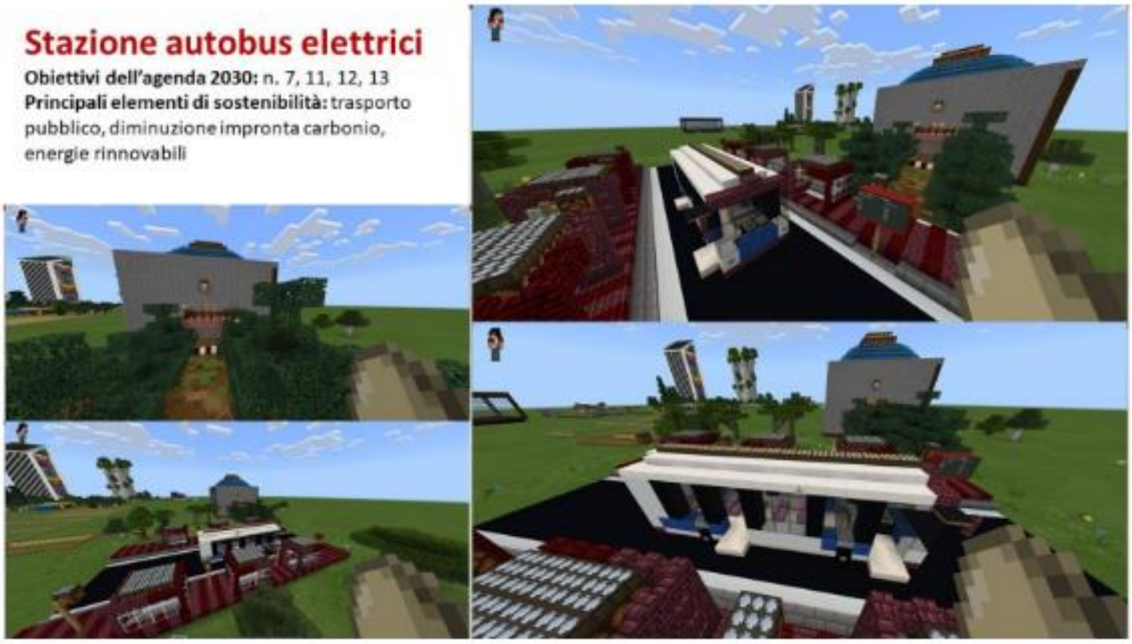
S	STUDENTS' SATISFACTION SURVEY
S1	Rate your level of agreement with each statement **Learning experience** ● This activity increased my learning focus ● This activity increased my knowledge ● This activity gave me engagement and enjoyment ● This activity improved my digital skills ● It was difficult to collaborate with other avatars in the virtual world (RS) ● The building activity helped me to better retain information found on the web and/or provided by the teacher ● I was really involved in the building activity ● I felt comfortable doing hands-on activities in the virtual world ● I prefer a classroom lecture than activity in a virtual world (RS)
S2	**From a technical point of view regarding the use of the platform, did you experience difficulties with the following aspects?** ● Internet connection ● PC requirements ● Communication (text chat and voice) ● Avatar movement ● Avatar customization ● Teleporting ● Camera movements and zoom ● Taking pictures (snapshot) ● Importing image in the world ● Interact with objects ● Manage the user inventory ● Prepare interactive panel and slide show ● Move, rotate, resize objects ● Link together different parts of an object ● Share objects between avatar ● Texturing faces of objects ● Make screencast videos ● Info web search ● Collaborate in the classroom with classmates ● Respect the project scheduling
S3	Suggestions to improve the educational path of the island
S4	Write 3 key messages that stick with you from the topics covered in Ecocity

Annex 3.A5.2. Detailed results of the post-activity test A5 (36 score test) by students and topics.

STUDENT / GROUP	SUSTAINABILTY	RENEWABLE SOURCES	ELECTRIC CONSUMPTION	EQUIPMENTS FOR ENERGY TRANSITION	CF	CRITICAL MATERIAL	GLOBAL SCORE (PT.)	GLOBAL SCORE (%)
mean	86.1	80.7	66.7	78.0	72.6	77.1	**27.5**	**76.5**
STD							6.7	18.5
n. questions	**3**	**8**	**5**	**7**	**7**	**6**	**36**	
1-W	3	5	2	3	1	4	18	50.0
2-W	2	7	3	5	4	2	23	63.9
3-W	3	7	4	6	6	6	32	88.9
4-W	2	8	1	1	3	0	15	41.7
5-W	3	7	4	7	7	5	33	91.7
6-W	3	8	3	7	6	5	32	88.9
7-W	3	7	4	6	6	5	31	86.1
8-W	2	7	4	7	7	6	33	91.7
9-W	1	7	3	5	4	3	23	63.9
10-W	3	8	4	7	7	6	35	97.2
11-W	3	7	4	7	7	6	34	94.4
12-W	3	8	4	6	7	6	34	94.4
13-W	3	7	4	7	7	6	34	94.4
14-W	3	7	3	7	6	6	32	88.9
15-W	3	8	4	6	6	5	32	88.9
16-W	3	8	5	6	6	5	33	91.7
17-W	3	7	3	3	6	5	27	75.0
1-C	1	1	2	5	2	2	13	36.1
2-C	3	7	2	4	1	4	21	58.3
3-C	3	4	3	6	1	5	22	61.1
4-C	2	6	2	4	4	5	23	63.9
5-C	1	4	4	3	6	3	21	58.3
6-C	3	2	4	7	6	6	28	77.8
7-C	3	8	4	6	6	5	32	88.9

CF = Carbon Footprint

Annex 3.A6.1. An overview on teams' work


Stazione autobus elettrici
Obiettivi dell'agenda 2030: n. 7, 11, 12, 13
Principali elementi di sostenibilità: trasporto pubblico, diminuzione impronta carbonio, energie rinnovabili


Diga ecosostenibile
Obiettivi dell'agenda 2030: n. 6, 7
Principali elementi di sostenibilità: energia rinnovabile (idroelettrica, fotovoltaico)

Bosco urbano e orto biologico

Obiettivi dell'agenda 2030: n. 12,13,15
Principali elementi di sostenibilità: mitigazione del clima, orto biologico urbano.

Hotel Arcobaleno

Obiettivi dell'agenda 2030: n. 7, 11, 12, 13
Principali elementi di sostenibilità: riduzione impronta di carbonio utilizzando pannelli solari e riforestando l'area circostante. Utilizzo di auto elettriche nelle strade adiacenti, limitazione del consumo di suolo.


Bosco Verticale
Obiettivi dell'agenda 2030: n. 7, 11, 12, 13
Principali elementi di sostenibilità: utilizzo pannelli solari, mitigazione microclima,

3.A6.2. Students’ post-activity test questionnaires (A6)

n.	STUDENTS’ INFO	Answers
G1	Gender	Male Female Prefer not to say
G2	Name of the school	open ended question
G3	Educational stage	Lower Sec. School Higher Sec. School
G4	Grade	K6, …, K12
G5	Section	A,…Z
G6	Students’ code (ask your teacher)	open ended question
T	**KNOWLEDGE TEST**	
T1	Put a check mark on the top five sustainable development goals that you think should be met in order to have a sustainable city	Multiple-select multiple-choice

T2	The Carbon Footprint of a product or service (e.g. public transportation) measures … • the amount of natural resources needed to produce that product or service • the amount of coal required to produce that product or service • the amount of greenhouse gasses emitted, especially carbon dioxide, to produce that product or service • the amount of trees needed to absorb the carbon dioxide emitted to produce that product / service	Single-select multiple-choice ✗ ✓ ✗ ✗
T3	Put in order of increasing carbon footprint - from smallest to largest (equal kilometers driven) ● Car ● Bike ● Airplane ● Train ● Bus	Ordering
T4	When electricity is consumed, is the emission of carbon dioxide always equal to	Single-select multiple-

zero? — choice

- Yes, always, because there is no combustion ✗
- Yes, but only if the electricity is produced from renewable sources (e.g. solar or wind) ✗
- NO, because even if electricity is produced from renewable sources, fossil fuels are almost always used to produce the materials needed to build solar and wind farms ✓
- NO, because electricity is obtained only from fossil fuels ✗

T5 To greatly reduce a city's carbon footprint, you would have to act mainly on those causes that produce the most greenhouse gases. On which of these items would you act to have a major decrease in greenhouse gases? Indicate at least the top 4. — Multiple-select multiple-choice

- Urban Greenery
- Transportation
- Internet connection
- Buildings
- Public infrastructures
- Waste management
- Manufacturing
- Education
- Turism

T6 Why you think it is important to act on cities to combat climate change. Indicate at least the top 4. — Multiple-select multiple-choice

- Because the population in cities far exceeds the population living in rural areas
- Because cities have the wealthiest people who can finance projects
- Because most of the world's energy is used in cities
- Because the politicians who make decisions are in the cities
- Because most of the world's natural and mineral reserves are consumed in cities
- Because there are more educated people in cities who can innovate
- Because more greenhouse gases are emitted in the city
- Because there is more tourism in cities

T7 — Multiple-select multiple-choice

- Put a check mark on the top five adjectives/names that inspire this image for you

- Dispersive
- Energy Efficiency
- Urban green.
- Innovation
- Chaos
- Urban mobility
- Expensive
- Relaxation
- Design
- Waste
- Integration
- Compactness

T8	What do you think are the main features in buildings similar to the Bosco Verticale in Milan? Place a check mark on 3 of these ● Elegant and spacious ● Close to transportation points (train station) ● Lower temperature and energy consumption ● conservation of biodiversity ● Landscape ● Improved air quality ● aesthetic beauty	Multiple-select multiple-choice
T9	To act sustainably, which of these actions of the so-called 4R would you take first? ● Repair ● Recycle ● Reduce ● Reuse	Single-select multiple-choice ✗ ✗ ✓ ✗
T10	To act sustainably, which of these actions of the so-called 4R would you take after all others? ● Repair ● Recycle ● Reduce ● Reuse	Single-select multiple-choice ✗ ✓ ✗ ✗
S	**STUDENTS' SATISFACTION SURVEY**	
S1	Rate your level of agreement with each statement **Learning experience** ● This activity increased my learning focus ● This activity increased my knowledge ● This activity gave me engagement and enjoyment ● This activity improved my digital skills ● It was difficult to collaborate with other avatars in the virtual world (RS) ● The building activity helped me to better retain information found on the web and/or provided by the teacher ● I was really involved in the building activity ● I felt comfortable doing hands-on activities in the virtual world ● I prefer a classroom lecture than activity in a virtual world (RS)	**Likert scale** 1 - Strongly disagree 2 - Disagree 3 - Neither agree or disagree 4 - Agree 5 - Strongly agree Questions labeled with RS are reverse scored
S3	Suggestions to improve the educational path of the island	Open ended questions

Annex 3.S.1: Students' satisfaction questionnaire results activity A1

EDUCATIONAL EXPERIENCE	Mdn	Mean	STD
***Learning experience* (x)**			
This activity increased my knowledge	4.5	4.4	0.7
This activity increases my learning focus	4.5	4.3	0.8
This activity gave me engagement and enjoyment	4.5	4.4	0.7
This activity improved my digital skills	4	4.4	0.5
I felt comfortable doing hands-on activities in the virtual world	4	4.0	0.7
The building activity helped me to better retain information and concepts about the subject	4	4.1	0.8
I felt engaged in the building activity	5	4.9	0.4
***Collaboration* (x)**			
(*) It was difficult to collaborate with my classmate	5	4.6	0.5
In the virtual environment it was easy for us to interact	4	3.9	0.8
VIRTUAL WORLD EXPERIENCE			
***Feeling* (x)**			
(*) Inside the virtual worlds I felt alone	5	4.9	0.4
(*) Inside the virtual world I felt under observation	4	3.8	1.3
(*) Inside the virtual world I felt tense / awkward	5	4.8	0.5
(*) Inside the virtual worlds I felt bored	5	5.0	0.0
Inside the virtual world I felt active	4	4.4	0.5
Inside the virtual world I felt immersed in the environment	4.5	4.5	0.5
Inside the virtual world I felt near my classmates despite the pandemic	4	4.5	0.6
Inside the virtual world I felt like I was actually building something	4	4.3	0.7
Inside the virtual world I forgot that I was "closed" at home (for the Covid pandemic)	3.5	3.9	1.0
Ease of use (xx)			
From a technical point of view regarding the use of the platform, did you experience difficulties with the following aspects?			
Internet connection	4.5	4.1	1.0
PC requirements	4	3.8	1.1
Communication with other avatars	5	4.8	0.4
Movement of the avatar	5	4.9	0.3
Interaction with objects	5	4.5	0.7
Avatar customization	4.5	4.4	0.7
Teleporting	5	4.5	0.7
Taking pictures	4.5	4.5	0.5
Uploading images	4	4.1	0.8
Movement of the camera (zooming in and out. changing perspectives. etc)	5	4.8	0.4
Managing inventory	4	4.1	0.7
Building	5	4.5	0.7
Comparison with distance learning classical lessons (x)			
Virtual laboratory activities are useful if you cannot attend the real ones	4	3.6	1.2
I participated in a more relaxed way than in a distance learning lesson	3.5	3.8	0.9
(*) A video lesson captures my attention more	4	4.0	0.8
(*) I prefer a distance learning lesson with respect to a lesson in the virtual world	5	4.4	0.8
(*) I think using virtual worlds for study takes up too much time	5	4.8	0.5
(*) I would have saved time if I had studied the topic from a book or from the internet	5	4.9	0.4

(x) Likert scale: 5 = Strongly Agree; 4 = Agree; 3 = Neutral / Undecided; 2 = Disagree; 1 = Strongly Disagree. The statements labeled with (*) are reverse scored.

(xx) (Likert scale: 1 = Extremely; 2 = Very; 3 = Moderately; 4 = Slightly; 5 = Not at all. Statements labeled with (*) are reverse scored.

Annex 3.S.2. Students' satisfaction questionnaire results activity A2a

Scale	# of items	Cronbach alpha score	Statement	Mean Likert scale Group S	W	Test U of Mann - Whitney *P* value
Quality of the learning scenario (x)	4	.70	The educational path is well organized and structured	4.0	4.3	.001
			The scenario is pleasant (graphics and colors /aesthetic)	3.3	3.7	.001
			Information in the island is clear and explanatory	4.0	4.2	.056
			The 3D learning objects and graphs helped me to understand concepts and data	3.9	4.1	.408
			On-line games are suitable for learning	/	4.3	/
			Different sections of the scenario were clearly labeled	/	3.7	/
Learning Experience (x)	3	.76	This activity increases my learning focus	4.1	4.4	<.001
			This activity produces better knowledge	3.9	4.3	<.001
			This activity gives me engagement and enjoyment	3.7	4.3	<.001
Ease of Use (xx) W group only	11	.71	From a technical point of view regarding the use of the platform, did you experience difficulties with the following aspects?			/
			Internet connection	/	4.4	
			Pc requirements	/	4.6	
			Communication with other avatars	/	4.5	
			Movement of the avatar	/	4.4	
			Interaction with objects	/	4.3	
			Avatar customization	/	4.2	
			Teleporting	/	4.5	
			Taking pictures	/	4.3	
			Uploading images	/	4.2	
			Movement of the camera ((zooming in and out, changing perspectives and so on…)	/	4.3	
			Managing inventory	/	4.2	

(x) Likert scale: 1 = Strongly disagree… 5 Strongly agree
(xx) Likert scale: 1 = Extremely, 2 = Very, 3 = Moderately, 4 = Slightly, 5 = Not at all.
Group S = 439 students; group W = 136 students

Annex 3.S.3. Students' satisfaction questionnaire results activity A3

Statement	Likert scale 1-2	3	4-5	No tested	Mean	Mdn	Cronbach alpha
Rate your level of agreement with each statement		**Quality of the learning scenario (*)**					
The educational path is well organized and structured	15.8	5.9	78.2		3.8	4	.761
The scenario is pleasant (graphics and colors)	12.9	16.8	70.3		3.7	4	
Time was enough to accomplish the mission	19.8	22.8	57.4		3.5	4	
There are not enough hands-on activities to do (RS)	15.8	26.7	57.4		3.7	4	
Information in the island is clear and explanatory	17.8	9.9	72.3		3.7	4	
On-line games are suitable for learning	18.8	13.9	67.3		3.6	4	
Different sections of the scenario were clearly labeled	11.9	15.8	72.3		3.9	4	
				Learning experience (*)			
This activity increased my learning focus	12.9	15.8	71.3		3.8	4	.852
This activity increased my knowledge	9.9	18.8	71.3		3.9	4	
This activity gave me engagement and enjoyment	11.9	19.8	68.3		3.8	4	
I felt comfortable doing hands-on activities in a virtual world	9.9	13.9	76.2		4	4	
Performing a mission motivated me within the virtual world	12.9	13.9	73.3		3.8	4	
I would use this virtual world to collaborate remotely with my classmates	16.8	17.8	65.3		3.7	4	
It was helpful to have the groups work on separate areas	15.8	19.9	64.4		3.7	4	
I prefer the classroom lesson with respect to one in a virtual world (RS)	13.9	25.7	60.4		3.8	4	
From a technical point of view regarding the use of the platform, did you experience difficulties with the following aspects?				**Ease of use (**)**			
Internet connection	10.9	9.9	79.2	0.0	4.1	4	.93
PC requirements	9.9	8.9	81.2	0.0	4.3	5	
Customizing my avatar	9.9	10.9	72.3	6.9	4.2	5	
Movement of the avatar	15.8	13.9	69.3	1.0	3.9	4	
Communication with other avatars	11.9	5.0	69.3	13.9	4.3	5	
Opening online games	12.9	9.9	77.2	0.0	4.1	5	
Browsing multimedia presentation	13.9	4.0	82.1	0.0	4.2	5	

(*) Likert scale: 1 Strongly disagree…. 5: Strongly agree. Statements labeled with (RS) are reverse scored
(**) Likert scale: 1 = Extremely, 2 = Very, 3 = Moderately, 4 = Slightly, 5 = Not at all.

Annex 3.S.4. Students' satisfaction questionnaire results activity A4

Statement	Likert scale			No tested	Mean	STD	Mdn	Cronbach alpha
	1-2	3	4-5					
Rate your level of agreement with each statement								
Quality of the learning scenario (x)								
The educational path is well organized and structured	6.3	12.5	81.3		4.1	4	1.1	
The scenario is pleasant (graphics and colors / aesthetic)	18.8	31.3	50		3.4	3.5	1.1	
Time was enough to accomplish the mission	18.8	31.3	50		3.3	3.5	1.2	
There are not enough hands-on activities to do (*)	18.8	37.5	43.8		3.4	3	1.2	
Information in the island is clear and explanatory	12.5	31.3	56.3		3.6	4	1.0	
On-line games are suitable for learning	25	18.8	56.3		3.4	4	1.3	
Different sections of the scenario were clearly labeled	0	18.8	81.2		4.1	4	0.7	
Learning experience (x)								
This activity increased my knowledge	18.8	6.3	75		3.8	4	1.2	
This activity increased my learning focus	12.5	12.5	75		3.8	4	1.1	
This activity gave me engagement and enjoyment	12.5	12.5	75		3.8	4	1.1	
I felt comfortable doing hands-on activities in a virtual world	0	37.5	62.5		3.6	4	0.5	
Performing a mission motivated me within the virtual world	18.8	25	56.3		3.4	4	1	
I would use this virtual world to collaborate remotely with my classmates	37.5	25	37.5		3.2	3	1.3	
I carried out the activity easily although other avatar were near me	18.8	25	56.3		3.5	4	1.2	
I prefer the classroom lesson with respect to one in a virtual world (*)	37.5	12.5	50.0		3.1	4	1.5	
Ease of use (xx)								
From a technical point of view regarding the use of the platform, did you experience difficulties with the following aspects?								
Internet connection	0	6.3	93.7	0	4.3	4	0.6	
PC requirements	0	18.8	81.2	0	4.1	4	0.7	
Customizing my avatar	0	12.5	81.2	6.3	4.3	4	0.7	
Movement of the avatar	0	31.3	68.7	0	3.9	4	0.7	
Communication with other avatars	0	25	68.7	6.3	4.2	4	0.9	
Opening online games	0	18.8	81.2	0	4.4	5	0.8	
Browsing multimedia presentation	0	18.8	81.2	0	4.2	4	0.8	

(x) Likert scale: 1 Strongly disagree…. 5: Strongly agree. Statements labeled with (*) are reverse scored

(xx) Likert scale: 1 = Extremely, 2 = Very, 3 = Moderately, 4 = Slightly, 5 = Not at all.

Annex 3.S.5a. Students' satisfaction questionnaire results activity A5

Statements	Students who accessed to the VW (W group) (n = 17)			Students who didn't access to the VW (C group) (n = 7)			U Mann Whitney Test (P value)
Statement	**Mean**	**STD**	**Mdn**	**Mean**	**STD**	**Mdn**	
This activity increases my knowledge	4.5	1.0	5	4.6	0.5	5	.71
This activity increases my learning focus	4.8	0.4	5	3.9	1.7	5	.349
This activity gives me engagement and enjoyment	3.9	0.8	4	3.1	0.7	3	1.000
This activity improved my digital skills	4.5	0.8	5	3.6	0.8	4	.019
It was difficult to collaborate with other avatars in the virtual world *(RS)*	4.2	0.7	4	/	/	/	/
The building activity helped me to better retain information found on the web and/or provided by the teacher	3.9	0.7	4	/	/	/	/
I was really involved in the building activity	4.3	0.8	4	/	/	/	/
I felt comfortable doing hands-on activities in the virtual world	4.1	0.9	4	/	/	/	/
I prefer a classroom lecture than activity in a virtual world *(RS)*	4.1	0.7	4	/	/	/	/

Likert scale: 1 Strongly disagree…. 5: Strongly agree. Statements labeled with (RS) are reverse scored

Annex 3.S.5b. Difficulties experienced by students in using the viewer Firestorm / carrying out the project's steps, activity A5

		Likert scale					
		1-2	3	4-5	No tested	Mean	Mdn
Tool / action	Total students	Students (%)					
Internet connection	17	11.8	11.8	76.5	0.0	4.1	5
PC requirements	17	0.0	11.8	88.2	0.0	4.5	5
Communication (text chat and voice)	17	0.0	17.6	82.4	0.0	4.4	5
Avatar movement	17	0.0	11.8	88.2	0.0	4.4	5
Avatar customization	17	11.8	11.8	76.5	0.0	4.0	4
Teleporting	17	0.0	0.0	100.0	0.0	4.8	5
Camera movements and zoom	17	0.0	11.8	82.4	5.9	4.6	5
Taking pictures (snapshot)	17	11.8	5.9	70.6	11.8	4.3	5
Importing image in the world	17	0.0	11.8	82.4	5.9	4.4	4.5
Interact with objects	17	5.9	5.9	88.2	0.0	4.5	5
Manage the user inventory	17	5.9	0.0	94.1	0.0	4.6	5
Prepare interactive panel and slide show	17	0.0	11.8	88.2	0.0	4.5	5
Move, rotate, resize objects	17	0.0	5.9	94.1	0.0	4.8	5
Link together different parts of an object	17	5.9	0.0	82.4	11.8	4.5	5
Share objects between avatar	17	0.0	17.6	70.6	11.8	4.1	4
Texturing faces of objects	17	0.0	0.0	94.1	5.9	4.7	5
Make screencast videos	24	4.2	12.5	66.7	16.7	4.2	4
Info web search	24	4.2	0.0	79.2	16.7	4.8	5
Collaborate in the classroom with classmates	24	0.0	4.2	95.8	0.0	4.9	5
Respect the project scheduling	24	0.0	16.7	83.3	0.0	4.3	4

Likert scale: 1-2 = Extremely / Very; 3 = Moderately; 4-5 Slightly / Not at all
Total students: 17 (Students who access to the virtual world), 24 (All respondent students)

Annex 3.S.6. Students' satisfaction questionnaire results activity A6

Activity	**Likert scale (% students)**			**Likert scale**		
Educational approach	**1 -2**	**3**	**4-5**	**Mean**	**STD**	**Mdn**
Statements						
This activity increases my knowledge	0.0	7.7	92.3	4.2	0.6	4
This activity increases my learning focus	0.0	7.7	92.3	4.7	0.6	5
This activity gave me engagement and enjoyment	0.0	7.7	92.3	4.7	0.6	5
This activity improved my digital skills	7.7	38.5	53.8	3.6	0.9	4
I felt comfortable doing hands-on activities in the virtual world	0.0	30.8	69.2	3.9	0.8	4
The building activity helped me to better retain information and concepts about the subject	0.0	7.7	92.3	4.2	0.6	4
I was really involved in the building activity	0.0	0.0	100.0	4.3	0.5	4
Designing a city gives an overview of environmental sustainability and highlights which problems a technician/engineer has to face	0.0	23.1	76.9	4.2	0.8	4
Inside the virtual world I felt near my classmates despite the pandemic	0.0	7.7	92.3	4.5	0.7	5

Likert scale: 1 Strongly disagree…. 5: Strongly agree.

Annex 3.V.1. QR codes to activity videos

Iron City

Sustainability Hub

Powerland FrameVR

Powerland Opensimulator

Ecocity

My sustainable city