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Enhancing Environmental Education Through Nature-Based Solutions

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Foreword

Environmental education is a fairly recent concept, although examples and applications have been described since early times. Even before writing or books existed, people observed natural processes and interacted with nature in a sustainable way. Their umbilical connection to nature depended on their respect for nature and warranted ecosystem preservation. Through time, knowledge acquired in this human-nature interconnection became the basis of environmental education. Nowadays, this connection has been lost somehow, although we still strongly depend on nature and its resources. Environmental education is a useful approach to remind us of this.

Environmental education, as it is currently addressed, emerged in the end of the XIXth century and is evidenced by its emphasis on environmental awareness and education programs focused on nature. Environmental education has been developed around two major pillars: the observation of natural processes and *in situ* experimentation. In this perspective, schools are the place of excellence to cultivate learning and knowledge acquisition in this area, expanding horizons beyond the classroom. Biological parks and gardens (zoos, botanical gardens), along with urban green areas (parks or woods), work as promotor areas for the development of environmental education activities, given their easy access. Learning with and on nature is essential to recover the lost human-nature connection, thus promoting environmental awareness focused on the conservation of biodiversity and natural ecosystems. Nature-based solutions provide demonstrations and real scenarios that change the perception of people (ex.: students), thus enhancing behavioural shifts towards more sustainable attitudes.

In recent years, a conservationist philosophy has re-emerged, amidst a technological era that has put enormous pressures on ecosystems, biodiversity and the world's climate. In part, this nature-nurturing approach stems from the appalling evidence of human impacts on nature, some of which are irreversible (ex.: habitat degradation, species loss). Indeed, many environmental quality indicators show that, unless conservation and restoration measures are implemented, the developmental model of modern societies may take a dangerous turn with important consequences for human well-being. World leaders have demonstrated this philosophy with hopeful claims to "make nature healthy again" or "bringing nature back into our lives". What are we waiting for to act? As individuals, all of us have important roles—individually and collectively—but visible and fast results can only be obtained with focused and concrete actions. This is where environmental education comes in, contributing to the learning process and shift in attitudes, namely exploring nature as a living laboratory. Increasing scientific literacy, by updating school curricula and enhancing environmental awareness, will warrant a healthier environmental future, based on green and blue infrastructures promoters of communities resilient to environmental change.

Environmental education is thus a powerful approach as a propeller of attitude shifts using (real) examples observed in nature, which should always be the main actress. Isn't nature the best and largest stage for acquiring environmental awareness?

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Contents

Chapter 1
Enhancing Environmental Education Through Nature-Based Solutions: An Introduction

Clara Vasconcelos and Cristina S. C. Calheiros

> *As members of the human species, we have the privilege of a high intellectual capacity (…) we have the responsibility to protect the long-term living conditions of the planet (…). This requires a well-qualified education applied to human societies worldwide.*
> Werner Arber (2020)

For decades we have been hearing the urgent need for environmental education, but many different activities have integrated that designation. From being focused in teaching *about* scientific knowledge, to teach *in* the environment or in the edge of the slogan of teaching *for* the environment, much has been done to prepare young citizens and the general population to care for our living planet. Nevertheless, some activities were (still are) more about communicating environmental issues to citizens instead of teaching students. Although both are requested for a common good, the environmental education aims to teach knowledge about the Earth system, to develop competencies like the environmental insight, critical thinking and decision making, and to enlarge the relevance of the environment for the perseverance of the life of humans on Earth.

When young children we hear at school that the sun is a star that "will end" after increasing its dimension and "warm" enormously our planet making impossible

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for humans to live on Earth. That is perhaps the first time we really think that the place where we live is not "a forever home", implying that if we want our specie to survive, one day, we must change to "another home". After that first astonishing recognition, we take more attention to scientific fiction movies, where space shuttles travel through the universe or researchers make scientific expedition to the moon or Mars in the attempt to find the "other home". But without Environmental Education children end up forgetting that we need to protect Earth, not only from the inevitable catastrophism ran by the rules of the universe, but mainly from our own attitudes and behaviours.

Mass media also disseminates some publicity to aware citizens about the dangerous of jeopardizing our planet by not protecting the environment or not saving endangered species, and enlightening about sustainable development goals. But literature is perhaps the eldest and most powerful way of communicating environmental issues. From "The Grapes of Wrath" published in 1939 by John Steinbeck and worth of a Pulitzer, to "Silent Spring" a best-seller environmental science book written in the 1962 by Rachel Carson, or to "The Road" a post-apocalyptic novel written in 2006 by Cormac McCarthy and awarded the 2007 Pulitzer Prize for fiction, many books raised objection, exposure and proclaimed the way we—the humans, are damaging our planet. By causing social calamities and perplexing and astonishing tragedies just by neglecting the environment, withdraw connection with nature and forgetting the holistic vision of the Earth system, the so called "rational specie" is putting in dangerous our life as a community and even our future on Earth.

Geology students learn about the physics and chemical characteristics of the Earth, not only by studying volcanos and rocks, but also by learning about seismic waves and anthropogenic behaviours. In biology they are taught about the soil and the sea, ecosystems and life, and biodiversity and climate change. Together with other environmental sciences, children and young adults learn at school about the flow of matter and energy and the holistic approach of the Earth system. But is by developing Environmental Education activities in a context of formal, non-formal or even informal Education that this ambitious process of learning gains roots and develops the environmental insight. This competency was first claimed by Nir Orion, a Professor and researcher from Israel who described it as the ability to perceive the interworking links between Earth subsystems and to reflect on one's own role in system Earth in order to continuously review geoethical behaviours [1]. Orion [2] claimed that to achieve that competency students must develop the understanding that the Earth system is made up of interconnected subsystems (geosphere, hydrosphere, biosphere, and atmosphere) that exchange energy and materials, and that humans are a part of the Earth system and must develop pro-environmental attitudes and behaviours being aware of its "laws" of cycling. That awareness requires geoethical values and principles to guide humans in their action. As stated by Peppeloni and Di Capua:

"… in their choices, humans must be supported by an ethical structure, a set of principles, and reference values that can guide their decisions and make them aware of the consequences of their interventions on natural processes and socio-ecological systems. Geoethics proposes principles and values capable of shaping the human perception of one's existential role in a gradually broader way, identifying and making explicit the ecological dimension of the human being, which does not deny the importance and value of humanity, whilst recognizing that its appearance and evolution on the Earth is linked to chance and contingency" [3].

In 2015, 195 countries had pledged to work together to produce Agenda 2030 that was built upon the Millennium Development Goals and Agenda 21. This plan of action comprises 17 sustainable development goals (SDGs) and 169 targets being many of them covered by environmental education. In the recent decades, formal sustainability education programs devoted to including rigorous systems of thinking, social interactions, and green principles have arisen, and their success is fuelling efforts to modify the school curriculum. These sustainable educational programmes include action integrating three pillars: the environmental, the social and the economic. Together with this emerging concept—sustainability—environmental education continues to grow proclaiming the so called pro-environmental behaviours, a notion very closed to pro-sustainable behaviours. Pro-environmental behaviours are described as actions performed by a single person with the explicit goal of conserving the natural environment, whether in its entirety or in specific ecosystems, from the detrimental effects of human activity [4]. Sustainable behaviours are often confused with pro-environmental behaviours, and although the first includes the social and economic foundations as well, both aim to lessen humans' environmental effects. Kaiser and collaborators [5] wrote an article about "*Ecological behavior and its environmental consequences*" where they refer alternatives to ecological and non-ecological behaviours by contrasting behaviours' environmental consequences with the comparable effect of a reasonable alternative, being the latest more environmentally friendly. But many are the articles that publish lists of pro-environmental behaviours for sustainability *versus* traditional ones persuading the readers to change routines and habits. But what influences individuals' pro-environmental behaviours?

The determinants of pro-environmental behaviours have been largely studied and published. According to some authors [6] three categories of factors influence people environmental behaviours: sociodemografic (age, education, income, household structure, gender); psychological determinants (beliefs, attitude, awareness, norms, values, identity, environmental knowledge, environmental concern, emotions, habits, locus of control & personal responsibility); others (peers, sanctions, self-well-being…). Without the intention of being exhausted, in the study of pro-environmental behaviours, sociodemographic characteristics such as gender, age, level of education, site of living, and even economic status have been of particular interest. In terms of gender and education, studies have indicated that women and those with greater levels of education are more likely to engage in pro-environmental behaviour. This can be explained by women's greater emotional involvement with environmental issues, as well as their willingness to cooperate and change. Furthermore, research reveals that younger people, as well as persons with more education, have higher levels of environmental care and concern. As expected, the possession of environmental knowledge and environmental concern positively impacts and increases pro-environmental behaviours [6].

But to achieve results it is also needed to develop creative global citizens of tomorrow, who idealistically are engaged in really environmental problems of the world and will develop social alternatives to our common way of living. As mentioned by Hazenberg and collaborators "there is a considerable body of academic and grey literature exploring the role of the higher education sector globally in driving social innovation" [7]. Given that society's capacity to act in the face of environmental and other issues is being honed, social innovations strive to enable people to drive change themselves. If, as stated by Heiskala "the most successful social innovations result in significant increases in the collective power resources of the society" [8], then we all must pursue that the education of the youngest generation is focused in environment and sustainability. Some social innovation that helped to solve environmental issues, like Nature-Based Solutions (NBS), are presently included in Environmental Education activities.

The European Commission has defined NBS to societal challenges as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions." [9]. Four key goals have been identified for NBS to be addressed [10]: (i) supporting sustainable urbanization (though economic growth and enhancement of human well-being, while making the urban area more attractive), (ii) restoring degraded ecosystems (improving the resilience of ecosystems and increasing their ecosystem services), (iii) climate change adaptation and mitigation (provisioning of responses to enhance carbon storage), and (iv) improving risk management and resilience (delivering greater benefits than conventional approaches and enabling synergies in reducing multiple risks).

Societies are facing a number of serious challenges including population growth, resource demand, climate change, and degradation of ecosystems that have repercussions on the economic, social and environmental pillars of the sustainable development. In order to cope with these challenges, it is imperative that a transformation of territories occurs using a holistic approach [11, 12]. Specially alarming is the report from Intergovernmental Panel on Climate Change (IPCC) [13] that most climate change effects are unprecedented and irreversible in the Earth system with repercussions to humans' life quality and wellbeing. In this context, it is important to look back to nature and to find solutions (nature-based) in order to increase the resilience and adaption capacity of the societies as well as protecting and restoring the ecosystems, with the necessary economic growth without further compromising the planetary boundaries. Having that in consideration is of outmost importance to shift from the linear economic model (i.e., "take-make-use-waste") to a circular model, where the target is to fulfill the way we meet our current needs, but through the use of less raw materials and natural resources, and consequently the reduction of the environmental impacts, such as greenhouse gas emissions [14].

Nature-based solutions are facilitators towards the transition to circular economy and resourceful cities. For shifting to circular management of resources with NBS the following urban circularity challenges (UCC) are considered [12]: (i) Restoring and maintaining the water cycle (by rainwater management), (ii) Water and waste treatment, recovery and reuse, (iii) Nutrient recovery and reuse, (iv) Material recovery and reuse, (v) Food and biomass production, (vi) Energy efficiency and recovery, and (vii) Building system recovery.

In order that NBS work effectively, are implemented adequately and are embraced by the communities, is necessary to understand the Earth system, the natural processes and have a holistic insight of this approach. This way is possible to turn environmental, social, and economic challenges into innovation opportunities, pursuing job creation, growth and quality of life, while tackling the global environmental issues.

The NBS concept is increasingly being developed, applied and referred in scientific literature and within governmental and non-governmental policies and programmes [e.g., 11, 12, 14, 15, 16]. Concerning education, this concept remains largely unexplored, where resources, contents and supportive programmes are missing from formal and informal education programmes at different educational levels. Nevertheless, efforts are being done in developing tools, courses and other frameworks (e.g., http://www.scientix.eu/pilots/nbs-project) as also supportive programmes (e.g., grant: Inside and outside: educational innovation with nature-based solutions: https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl6-2021-communities-01-06) towards the inclusion of this concept. This is why the present book is so fulcra and timely appropriate, shedding light on approaches to enhance "Environmental Education" through "Nature-based solutions", besides providing case studies and implemented examples worldwide.

This book has 24 chapters organized in four sections. Section one has four chapters clarifying the definition and scope of *Environmental Education.* The second part is about *Environmental Education and it´s Teaching* and has seven chapters. *Environmental Education and Social Engagement* is developed in five chapters integrated in the third part. The last section of the book, with seven chapters, is focused in *Nature-based solution* and how they can enhance Environmental Education. With the contribution of authors from 18 countries (Austria, Brazil, Cabo Verde, Chile, Check Republic, Germany, Greece, Iceland, Israel, Italy, Macao SAR, China, Portugal, Serbia, Slovenia, Spain, Switzerland, Turkey, United Kingdom), this book was conceptualized under the belief that the youngest generation is an excellent social innovator and that young people will be the leaders of tomorrow. They are embedded in today´s environmental issues and the first ones to act for humanity wellbeing. We believe that they must be in the core of everything we do as a human society and, for them, we must continually improve Environmental Education.

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Part I
About Environmental Education

Chapter 2
Training and Dissemination About the Environment: Keys to Impulse the Abiotic Component of Environmental Education

Amelia Calonge, Eugenio Molina-Navarro, and Pedro Alfaro

Man and the Earth share a common heritage, of which we and our governments are but the custodians. Each and every human-being should understand that the slightest damage could lead to irreversible losses for the future. In undertaking any form of development, we should respect the singularity of this heritage.
Digne-les-Bains declaration (Digne, France, 1991)
Declaration of the Rights of the Memory of the Earth

Abstract Environmental education has a primarily biotic approach, but there is no scientific literacy without also understanding the abiotic component of the environment. The main objective of reducing the negative environmental impact of humankind is possible with complete information on the environment. Fortunately, proposals that integrate abiotic resources into the environment and, more specifically, geological information are increasingly frequent in many countries. Dissemination activities and strategies such as specialized mass media (scientific documentaries), science museums, and natural parks, among many others, are very helpful, but they only reach a small part of society. Therefore, compulsory education is essential for offering an integrated and multidisciplinary vision of environmental education because it is addressed to all citizens. We describe some difficulties and strategies to implement the abiotic component of environmental education, especially with several

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activities developed in Spain. Natural protected areas are an extraordinary resource for environmental education, but developing activities in schools or neighbourhoods also offers significant benefits.

Keywords Deficiencies in environmental education · Geoscientific literacy · Compulsory education · Dissemination activities · Earth sciences teaching · Teachers training

Introduction

It is not easy to define environmental education; the diversity of approaches, objectives, strategies, purposes, and scenarios means that there is no single conception. Among the multiple definitions of "environment", the Spanish Network of Environmental Authorities defines it as the natural, social and cultural values in a certain place and time, which have an influence on the material and psychological human life and on the future of the next generations [1]. Additionally, the White Book for Environmental Education released by the Spanish Ministry of the Environment [2] points out the "Environmental Education" definition given at the UNESCO-UNEP International Congress on Environmental Education and Training held in 1987 in Moscow. It defines Environmental Education as a permanent process in which individuals and communities acquire awareness of their environment and learn the knowledge, values, abilities, experience, and determination to act, individually and collectively, to solve present and future environmental problems. All the definitions, both traditional and recent, have in common the recognition of the environmental crisis and the need to find solutions.

Therefore, special emphasis should be placed on including Environmental Education contents in the education system, as reflected in the abovementioned White Book, which states that the educative system should commit to guaranteeing the real presence of an integrated environmental education model based on values education [2]. This implies that all aspects of the natural environment should be included when addressing environmental education, i.e., both Life Sciences and Earth Sciences.

However, in undergraduate education, the focus is often placed on life sciences. Most environmental education plans and programs have a clear biotic approach, with a majority of activities and proposals promoting knowledge and awareness about the conservation of flora and fauna. Unfortunately, Earth Sciences are frequently overlooked, ignoring educative proposals towards raising awareness about geological heritage and its conservation. Without an understanding of the relevance of abiotic natural resources, students will not be able to understand the environmental impacts, natural hazards or the basis of environmental preservation and restoration, among other key environmental education concepts.

This lack of Earth Sciences improves in Spanish university education. Looking at the BSc in Environmental Sciences study programmes across Spain, both Earth and Life Sciences, together with other disciplines (other experimental sciences and diverse social sciences), tend to reach an equilibrium, better representing what the environment is meant to be. However, this equal focus is not always the case. As an example, the three BSc programmes in Environmental Sciences from Madrid's public universities are analysed. At the University of Alcalá, 31 European Credit Transder System (ECTS) credits are taught in basic and compulsory Earth Sciences (geologic, hydrologic, and atmospheric sciences) courses, versus 32 ECTS credits in Life Sciences courses. At King Juan Carlos University, these numbers are 28 and 33 ECTS for Earth Sciences and Life Sciences courses. The Autonomous University of Madrid shows less equality between disciplines, with 21 ECTS for Earth Science courses and 39 ECTS. In addition, a number of subjects combine both, sometimes also with Social Sciences (e.g., Techniques Applied to Fieldwork, Environmental Impact Assessment, Land Planning or Management and Preservation of Natural Resources).

It seems obvious then that the focus should be placed in compulsory education. Over the past few years, several reforms in the educational system have been implemented in compulsory education in Spain. The most recent reform will be a new organic law that will modify the present law (acronym in Spanish, LOMLOE). The previous education law, the Organic Law on Improvement of Education Quality (LOMCE, Spanish acronym), established a curricular framework in which scientific subjects had lost specific weight with respect to the previous law. These changes in the legislation on education have not always been favourable in terms of including Earth Sciences and particularly geological contents when addressing Environmental Education.

Under this scenario, it seems reasonable to discuss Earth Sciences and Geology in preuniversity education. What and which geology is taught in compulsory education? Who teaches Earth Sciences and Geology in compulsory education? How are these subjects taught? What do we know about the geology of our environment?

In this work, we analyse the situation of the abiotic components of Environmental Education and Compulsory Education, with their present difficulties and several strategies for improving their integration. In addition, we stress the importance of using geological resources in promotional environmental educational activities by describing several experiences in Spain. Finally, we highlight the knowledge of the local territory as a powerful tool for Environmental Education that develops attitudes and behaviours about sustainable development.

Why is an Abiotic Approach Important in Environmental Education?

It is impossible to understand the environment without also understanding its abiotic component. A holistic perspective is necessary in which the earth is understood as a system where interaction takes place between its components, the stress being on the interaction between mankind and the planet.

How is it possible to find solutions for environmental problems such as climatic change, water scarcity, soil erosion and degradation, natural disasters, sustainable mining or ocean acidification, among many others, without an understanding of the abiotic component of the environment? Knowledge of geosciences is important in the daily lives of all citizens.

Earth science literacy is essential for a complete understanding of the present environmental crisis. The great advantage of formal education is that it is addressed to all citizens. Providing a complete and integrated vision of our planet is necessary in compulsory education.

In addition, complementary dissemination activities, despite being addressed to a voluntary community, are very helpful for increasing social knowledge about Earth Sciences and Geology.

Training of the Abiotic Component in Compulsory Education: Difficulties

Earth Sciences and Geology in pre-university education have a complicated situation in many countries, mostly related to scarce content in the curriculum, the excessive use of textbooks with a classical format or an insufficient training of teachers. Next, the main difficulties are described and analysed.

Deficit of Abiotic (Geological) Contents in Compulsory Education

Earth Sciences or Geology do not exist as separate subjects in secondary school in most countries. Geology is included indirectly through other subjects and educational activities such as Environmental Education [3].

The analysis in different countries (Portugal, Italy, Greek, Germany, United Kingdom, France, Austria, Brazil, Argentina, Chile, Uruguay, Colombia, etc.) shows that, at the lower levels, geology is studied as a discipline included in a generic science subject or within other "twin" or conceptually close subjects, such as biology, environmental sciences or geography.

A consequence is the progressive decrease in the amount of geology being taught in schools, both in time assigned and in content shared in science programs. In many schools, geological content is not taught or is taught quickly to devote more time to other subjects considered relevant by teachers in the processes for incorporation into university studies. This reality could bring highly negative consequences to the university background and future research and knowledge of the environment [4].

Non-specialized Teachers without an Adequate Training

Although in secondary schools, subjects are assigned to specialized teachers, there is a shortage of geology teachers. In fact, in some schools in Spain, almost all science-related courses are taught by biology specialists. In the case of Greece, geology-geography is taught by other specialists, such as mathematicians and household economy teachers [5].

This should not be a problem with adequate and continuous training, but the truth is that there is a lack of updated geological training for these teachers related to new scientific advanced contents and new pedagogical methods.

Textbooks with Classical Contents

It is well known that the main teaching resource at pre-university educational levels is the use of textbooks. For this reason, the way textbooks present geoscientific content is a determining factor of subsequent geoscientific education at this educational level.

It is known that there are important geoscientific shortcomings among young people who complete their compulsory education. One of the main reasons for these deficiencies is "late and slow updating of textbook contents". In the particular case of the abiotic component of Environmental Education, the contents and didactic resources have little social impact and are unattractive.

Strategies for Improving the Integration of Abiotic Approaches in Compulsory Education

Vindication of Earth Sciences and Geology in Curricula

It is necessary to change the present situation of Earth Science and geological content in compulsory education. In addition to increasing geological content, it is essential to improve organization during different educative stages and to offer more attractive content, demonstrating that the geosciences are important in the daily lives of all citizens.

In 2011, the Spanish Earth Science Teachers Association (AEPECT, Spanish acronym) invited all scientific organizations related to geology and its teaching to form a study commission to review the status of Earth Science in compulsory education and propose a curriculum to define the "Framework of Principles of Geoscientific Literacy" that should be taught.

The result was the document "Earth Science Literacy" [6]. This document describes the basic knowledge every student should have when finishing their compulsory education. The proposal stems from a holistic perspective in which the earth is understood as a system in which interaction takes place between its components, the stress being on the interaction between mankind and the planet. In this way, "Earth Science Literacy" is synthesized in the following next ten big ideas: (1) the earth is a complex system in which rocks, water, air, and life interact; (2) the origin of the earth is linked to the origin of the solar system, and its long history is recorded in the materials that compose it; (3) materials on Earth continually originate and change; (4) water and air make Earth a special planet; (5) life evolves and interacts with the earth, so that life and the earth modify each other; (6) plate tectonics is a comprehensive and integrative theory of the earth; (7) external geological processes transform Earth's surface; (8) humanity depends on planet Earth for its resources and must do so in a sustainable way; (9) some natural processes pose risks to humanity; and (10) scientists interpret and explain how the earth works based on repeatable observations and verifiable ideas.

The approved document was delivered to the Spanish Ministry of Education, disseminated and published in a special issue of the journal "Enseñanza de las Ciencias de la Tierra", in 2013: https://www.raco.cat/index.php/ECT/article/view/274145/362238.

We must highlight that the most attractive and tangible geological contents are essential to stimulate students' interest in geosciences [5]. The aforementioned ten big ideas are very attractive, but ideas 1, 3, 4, 5, 7, 8 and 9 are essential in Environmental Education.

Training for Teachers

Taking into account that most Earth Sciences and Geology teachers are not specialists, an intensive training program is essential. Educational authorities must offer courses, educative conferences and meetings and encourage the participation of teachers. In addition, another objective should be the inclusion of a specialist in Earth Sciences in each secondary school.

New Strategies for Education

It is necessary to understand that changing the way geology is taught must have an impact on the methods applied for its teaching [3]. In this way, research in innovation is committed to educational methods in which the didactic, scientific, and ludic aspects converge so that students have the leading role in their learning.

The challenge of teaching in the twenty-first century starts from a didactic change from traditional teaching methods to new formulas of teaching that are more participatory. We will comment on some of them based on the positive results after their implementation in teaching geology and/or Environmental Education.

On one hand**, gamification** is a tool currently used in pedagogy and requires using the psychology of the game, its mechanics, and its dynamics in nonludic environments such as a classroom or a laboratory. Particularly, we have gamified several laboratory practices by converting the learning process into a game that combines challenges and fun, looking for the motivation of the students while they acquire study habits [7]. The gamification elements include presentation of assumptions, use of avatars, division in levels, missions, badges, points, timelines, and immediate feedback [8]. This strategy favours the acquisition of certain skills, contents and competencies for students [9].

On the other hand, learning experiences generated with **educational robotics** [10] result in the active participation of students, since they are given great prominence when carrying out different activities such as the design of different dinosaurs or seismometers. Motivation is favoured because the students focus their attention on the game and, from it, they enjoy acquiring different knowledge in a playful way.

Another successful didactic model in classrooms is the **5E Instructional Model** [11]. It is an educational strategy that is articulated in five levels [12]: (1) Teachers help students become **engaged** in a new concept through activities that promote curiosity and elicit prior knowledge. (2) Use **explanations** to help students use prior knowledge to generate new ideas. (3) **Explore** questions and possibilities, and design and conduct a preliminary investigation. (4) Through new experiences, the students apply their understanding of the concept by the **elaboration** of new activities. Finally, (5) the **evaluation** phase encourages students to assess their progress towards achieving the educational objectives. This model plays a significant role in the curriculum development process as well as the enactment of curricular materials in geoscience classrooms.

Finally, the demand for citizens actively prepared to face challenges due to the accelerated changes that have occurred in the social, cultural, technological and economic framework constitutes the starting point of **STEM education** (English acronym of Science, Technology, Engineering and Mathematics). It can be affirmed that all the work that we carry out in the context of STEM [13] education will lead to the development of student competencies that favour the active participation of people in society, continuous access to knowledge, learning, and the development of critical and reflective thinking and values. In fact, the arts have been included (plastic, visual and musical arts) in this paradigm, forming **STEAM** (science, technology, engineering, arts and mathematics). The objective is to make knowledge even more complete and complementary, developing aspects directly related to creativity and the aesthetic and artistic senses, and thus making sciences and arts motivating subjects for more students.

Field Activities: The Best Educational Strategy

In addition to these new educational methods and strategies, field work is the starting point of any environmental study. Learning activities outside the classroom, where students can connect directly with nature, are the best resource for Environmental Education [14–16], among many others. These geological field activities, as a complement to biotic issues, can contribute to enriching environmental education programmes.

Thematic routes, geotourism sites, geoparks, visitor centres of natural protected areas, and paleontological and/or geological museums have increased in recent years in Spain. They become a useful resource for teachers in the preparation of field activities.

We must not forget that the preparation of and accessibility to points of environmental interest directly increase their risk of destruction and plundering. It is necessary to implement preparation measures, teaching and tourist adaptation, and appropriate protection and maintenance measures. These aspects are fundamental for the protection and preservation of geological heritage. It is also an extraordinary opportunity to potentiate new citizen behaviours, promoting its sensitivity to geoconservation.

Educational Programs, Projects and Activities

During the last two decades, several initiatives have been addressed to students and teachers of compulsory education to motivate and improve the teaching of earth sciences and geology. Hereby, we describe some examples with different formats and methods but with very positive attributes.

– The **International Earth Science Olympiad** (IESO) is an initiative that started in 2007 in line with other actions implemented to mark the International Year of Planet Earth. Spain joined this initiative in 2010, and thanks to the support of AEPECT, the first Spanish Geology Olympiad was held on a national level in 2010 to select the four best representatives to participate in the IESO 2011. The main purpose of geology Olympiads is to encourage students in the acquisition of knowledge on earth sciences by highlighting its importance in the current world, promoting its progress and disclosure, and, in turn, encouraging students to attend university courses related to this subject. In fact, geology Olympiads have been one of the initiatives of a slow but steady recovery of the number of students interested in pursuing earth sciences degrees [17].
– **Stop Disasters!** is a resource management strategy game designed to teach about natural disasters as well as methods of reducing casualties and damage because of these disasters. The player assumes the role of a contractor in charge of improving the area's response to specific natural disasters. Within a set time limit, the player must manage their resources to construct and reinforce local buildings, conduct training, and purchase warning systems to help make the community safer. https://www.stopdisastersgame.org/.

– **Earth Learning Idea** (ELI) is an open-access Earth-related teaching platform, designed to provide practical resources for teachers and teacher trainers worldwide. Some of these activities require the use of some basic school laboratory equipment, and some include abstract ideas. Each activity is designed to create student participation for maximum learning. All activities are free to download, and most require minimal cost and equipment. https://www.earthlearningidea.com/.
– **Schools Tune into Mars (STIM)** is an Erasmus + Project funded by the European Union. Its main objective is to provide teaching materials related to Earth and Space Sciences. For the first time, through STIM, secondary education teachers together with their students will be able to analyse seismic data from Mars simultaneously with scientists. https://insight.oca.eu/fr/stim-resources.

How to Promote Environmental Education Experiences Using Geological Resources. The Experience of Spain

Although dissemination activities are voluntary, they are useful for increasing environmental sensitivity and social scientific literacy. In recent decades, many strategies have been developed. Fortunately, many activities have been developed in recent decades, contributing to the integration of abiotic components into environmental education. One strategy is related to activities developed on commemorative days, with special impact on social media. Some examples are:

– **World Wetlands Day**. The commemoration of the World Wetlands Day on the 2nd of February is becoming one of the most successful Environmental Education initiatives in Spain and around the globe, combining dissemination of both Earth and Life Sciences as life in those ecosystems cannot be understood without also understanding the hydrological and geological counterparts. In 2021, and despite the COVID-19 pandemic, 1207 events were planned 1207 worldwide, 62 of which were in Spain. https://www.worldwetlandsday.org/.
– **World Water Day**. Another outstanding initiative of Environmental Education could not be understood without its Earth Science component. Held on 22 March every year since 1993, thousands of activities are planned towards this day with a varying motto each year. Its commemoration matches up with the celebration of the Iberian Day of Continental Water, an initiative that was started in 2020. https://www.worldwaterday.org/.
– **Science in Action**. A science competition throughout the whole country included a geology section initiated ten years ago. It has several categories, including (1) science teaching materials, (2) articles about science communication, (3) science performances, (4) science videoclips, and (5) science laboratory experiments. https://cienciaenaccion.org/.
– **European Researchers' Night**. The European Researchers' Night takes place yearly, typically in September. It is addressed to the general public, with special

focus on families and students. Activities related to Earth Sciences and Geology are growing every year.

A special mention should be made of the Spanish activity Geoloday. The **Geolodays** are Geology promotional initiatives across Spain that consist of a field trip guided by teams of geologists and other environmental scientists. They are coordinated by the Spanish Geological Society (SGE), with the support of the Spanish Earth Science Teachers Association (AEPECT) and the Geological and Mining Institute of Spain [18]. They started on a very small basis in the province of Teruel (2005), and currently, there are simultaneous Geolodays in every Spanish Province to increase their visibility in the media [19]. These field trips are open to everybody, regardless of their previous knowledge (Fig. 2.1). The main aims of these activities are (a) observing the local surroundings through "geological eyes" and understanding the effects of some geological processes acting in and upon the earth's surface, (b) discovering and knowing our geological heritage and raising awareness of its importance and the need to protect it, and (c) sharing what geologists do and appreciating how they, as scientists and professionals, contribute to a better society and public welfare. The success of the last events (Table 2.1), with more than 6,000 people enjoying geology across Spain and their intentions to participate in future events, encourages us to continue in this direction to make the Geolodays the annual festival of geology. More information is available at: (http://www.sociedadgeologica.es/divulgacion_geolodia.html).

The **Sponsor of a rock** project [20] should also be highlighted. This is a strategy for protecting the geological heritage to involve society in geo-conservation: http://www.geologiadesegovia.info/apadrinaunaroca/.

Environmental Education must include actions based on the Universal Design for Learning that can be integrated into the Sustainable Development Goal (SDG4) of the 2030 Agenda [21]. **Geodivulgar** is a pioneering project for the dissemination of geology among people with functional diversity in Spain [22]. Therefore, portable kits were prepared so they could allow combining indoor and outdoor geology communication activities in areas with a limited cultural offer for people with functional diversity. This project also offers geological story contents such as "once upon a time the geology" or illustration contents "travelling in pretty times", talks, workshops, educational games, field activities, etc. https://www.ucm.es/geodivulgar/.

Local Setting, a Powerful Tool for Environmental Education

Natural protected areas are an extraordinary resource for environmental education. Scenic landscapes with close contact with nature offer an opportunity to escape urban life and to favour nature awareness, among many other advantages. Museums, visitor

Fig. 2.1 Participants in Geoloday Alicante 2017 celebrated in Tabarca Island (**a**) and Geoloday Alicante 2018 in Crevillente Mountain (**b**). The total participation was 1200 and 1500 people, respectively

centres or interpretative book guides have played a remarkable role in increasing awareness of conservation initiatives.

In relation to the abiotic component of environmental education, the creation of global network geoparks offers a good opportunity for dissemination of the geological heritage and conservation of the territory.

Developing activities in the neighbourhood of the school, although they are not as spectacular as natural protected areas or geoparks, offers complementary benefits

Table 2.1 Participants in the activity Geoloday-Alicante showing the great interest in the abiotic component of the environment. Places are limited since 2017 due to high demand

Year	Site	Offered routes	Staff, guides	Participants	Limited places
2008	Serra Gelada natural park	2	14	635	No
2009	Aitana mountain	1	26	800	No
2010	Alicante town	1	40	1000	No
2011	Moraig beach	1	80	1065	No
2012	Pinoso diapir	1	100	1500	No
2013	Santa Pola reef	1	110	2500	No
2014	Orihuela mountain	2	120	1850	No
2015	Alcoy mountain	2	110	1500	No
2016	Agost KT boundary	2	105	3000	No
2017	Tabarca island	1	100	1250	Yes
2018	Crevillente mountain	1	100	1500	Yes
2019	Busot Canelobre caves	1	100	1150	Yes
2020–2021	Alicante province	10[a]	30[a]	400[a]	Yes[a]

[a] Small groups due to COVID-19 pandemic

for Environmental Education. The discovery of geological information about coasts, rivers or mountains around schools or towns offers basic knowledge for a critical analysis of environmental problems in the daily life of citizens and students and is one of the most powerful tools for education.

A successful example is Geogymkhana-Alicante [23]. Organized annually since 2012, nearly 10,000 students from 90 secondary schools have participated. This outdoor multigame activity for secondary schools combines scientific, playful and didactic elements throughout a 3 km-long coastal itinerary near the city of Alicante (Fig. 2.2). The route is relatively close to numerous secondary schools, allowing students to learn about their local geoheritage. This activity stimulates student interest in geoscience and the environment, which is essential to the future preservation of geoheritage. Some analysed issues are [24]: (1) evaluation of the visual impact related to the regeneration of the San Juan beach, enhancing the relationship between geological elements and environmental values, (2) analysis of the vulnerability of fragile outcrops of the Quaternary fossil beach deposits, and (3) raising awareness about the loss of scientific data when fossils are collected.

Fig. 2.2 Photographs of participants of Geogymkhana-Alicante. **a** and **b** The activity stimulates the student interest in local environment, enhancing the relationship between geological elements and environmental values. **c**, **d**, **e** and **f** The activity combines scientific, playful, and didactic elements. **c** "Geocharades" activity. **d** Participants solving the final enigma in the "Geological History". **e** Students in the "Geological Time Race". **f** Students building a human stratigraphic section

We need to develop pro-environmental behaviours not only in natural protected areas. This positive attitude towards the environment must be maintained daily, starting with the protection of our closest territory.

Conclusion

Is it possible to reduce the impact of human behaviour on our planet without basic knowledge of how the planet works? Climatic change, water scarcity, soil erosion and degradation, natural disasters, sustainable mining and ocean acidification, among many other environmental problems, require basic knowledge of earth sciences.

There is no environmental education without including the abiotic component of the earth. Earth science literacy is essential for a complete understanding of the present environmental crisis.

It is necessary to improve the present situation of earth science and geological content in compulsory education. In addition to increasing geological content, it is essential to improve organization during different educative stages and to offer the most attractive content, demonstrating that the geosciences are important in the daily lives of all citizens. New pedagogical methods are needed, including the best strategy, which is the organization of multidisciplinary fieldtrips.

Although dissemination activities are voluntary, several examples described in this work prove that they are useful to increase environmental awareness and society scientific literacy, particularly Earth Sciences literacy.

We need to reach pro-environmental behaviours not only in natural protected areas. This positive attitude towards the environment must be maintained daily, starting with the protection of our closest territory.

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Chapter 3
Educating to Deliver Environmentally Focused Social Innovation

Richard Hazenberg

Abstract The United Nations 2030 Sustainable Development Goals provide clear direction for how we can develop a more sustainable world by 2030 and beyond, with key performance indicators across 17 goals. One of these goals, SDG15 Life on Land, aims to 'protect*, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss'* (United Nations https://sdgs.un.org/topics/forests, 2021) and this has clear implications in the UK for the management of ancient woodland. In England ancient woodland is identified as those areas of woodland that have existed since the seventeenth century and they remain crucial areas of natural habitat and biodiversity in the English countryside (Woodland Trust https://www.woodlandtrust.org.uk/trees-woods-and-wildlife/habitats/ancient-woodland/, 2021). However, outside of these ecosystem benefits, they also provide an environment for educating young people about sustainability and for delivering social innovations that support local communities socially and environmentally. This chapter explores how education within an ancient woodland setting can help to promote environmental awareness, as well as supporting the creation of social impact. Utilising the case-study of a social enterprise in England that maintains ancient woodland and educates socially excluded young people, the chapter seeks to argue that the hybrid mission of the organisation combined with its unique environmental location, provides the perfect model for supporting socially disadvantaged individuals to become the 'changemakers' of tomorrow.

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The UN Sustainable Development Goal 4.7 states that 'By 2030, ensure that all learners acquire the 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'.

Keywords Environmental education · Social innovation · Changemakers · Ancient woodland · Social impact

Introduction

Education provides a critical means for developing the citizens of tomorrow and ensuring that awareness of and discourse around sustainability issues are developed. This approach to creating 'Changemakers' has been embodied in a global programme led by Ashoka[1] focused on creating a global movement within which individuals and communities can come together to solve social (and environmental) problems [3]. However, outside of such programmes, the concept of sustainability education remains under-developed [4], particularly with regard to social innovation. Indeed, much sustainability education is focused on the wider world of ecosystems, technology and institutional structures, ignoring the role that internalised, personal development can have [5]. This focus on reflective learning centred on place-based and experiential learning, is a fundamental aspect of best practice in social innovation education [6], which can provide fertile learning for practitioners seeking

[1] See: https://www.ashoka.org/en-gb/programme/ashoka-changemakers.

to deliver environmentally focused social innovation education. Such approaches to informing young people around sustainability issues are key in helping to developing informed and independent democratic citizens [7]. This chapter seeks to explore this through the examination of an environmentally focused social enterprise in England that delivers education to disadvantaged young people within an ancient woodland setting. The author argues that by engaging young people in place-based environmental social innovation in an ancient woodland site, young people can be empowered to become Changemakers and to better understand sustainability. The chapter begins with an exploration of the concepts of social innovation and social enterprise, before moving on to discuss environmentally focused social innovations. The literature review is then completed with an examination of social innovation and sustainability education, before the methodological approach and social enterprise case-study is described. The results are discussed in relation to sustainable development and the SDG 2030 agenda, set within a Weberian [8] theoretical framework centred on individual empowerment.

Environmentally Focused Social Innovation Education: The Context

Social Innovation and Social Enterprise

Social innovation is defined as 'changes in the cultural, normative or regulative structures (or classes) of the society which enhance its collective power resources and improve its economic and social performance' [9]. A key feature of social innovation is the empowerment of disadvantaged individuals that enables them to solve social and/or environmental problems that afflict their community (locally or globally) [10]. Social enterprise represents one form of social innovation and can be identified as self-reliant, independent organisations that deliver non-economic outcomes [11]. Whilst social entrepreneurship and social enterprise are forms of social innovation, it should be noted that social innovations can be created by a wide variety of stakeholders, including government, NGOs, charities, corporates and educators [12]. The key originality of social enterprise interventions to drive social innovations, lies in their hybrid approaches to delivering social, environmental *and* economic value, as part of their institutional logics and value propositions [13].

Social innovation has a dichotomy that lies at its heart, in that its increasingly seen as a globalised term and one that is used homogenously around the world, despite the fact that social innovation is in essence a localised construct that has unique meaning at community levels and is often utilised as a mechanism for resisting globalisation and the inequalities that this creates [14]. This is an important distinction to make, as research has identified that it is bottom-up led community social innovations that tend to have greater social impact than top-down driven approaches [15]. This tension is important to recognise when exploring social innovations centred on the environment and sustainable development, as the UN SDG framework represents a top-down approach to driving global sustainable development (albeit one that seeks to recognise local contexts). In this context, the SDGs provide a roadmap for sustainable development, but one that must be tailored locally in order to deliver truly impactful environmentally focused social innovations.

Environmentally Focused Social Innovation

Environmentally focused social innovations are becoming increasingly common, as communities, governments and transnational bodies seek innovative solutions to increasingly complex problems. The purpose of this chapter is not to provide an exhaustive account of these interventions, but examples can be found with regards to smart cities [16]; environmental funds [17]; coffee farming and production [18]; and reducing food waste [19]. Whilst traditionally, eco-innovations are characterised as emerging due to policy drivers, market regulation, market demand and cost-saving [20], environmentally focused social innovations are also driven by community action and demands, often embodied within the community leadership. Indeed, it is community leaders that can help to give voice to communities [21], especially those from disadvantaged backgrounds and these leaders can include educators and social enterprises. When considering how these community initiatives emerge as social innovations, it is important to acknowledge the role that social networks and social capital play in enabling the social innovations to develop [19, 21].

The importance of community network building and the role of educators in supporting and scaling social innovations is an important one. Hazenberg, Giroletti and Ryu [22] demonstrated the role that universities can play in this area as local anchor institutions when exploring social innovations in Asia. However, government and transnational frameworks can also play an important role in supporting the scaling of these social innovations and enabling place-based sustainable development [23]. This is because frameworks like the SDGs provide what Baker and Mehmood [23] identified as ‘governance frameworks’ that enable social innovation scaling by coordinating or focusing different stakeholders. Such networks are crucial to social innovations as they act as a mechanism for empowering people at a wider level, whilst allowing a ‘zoomed in’ function for developing change locally [24]. This chapter argues that this is where social enterprises can play a powerful role in driving forwards such environmentally focused social innovations, by acting as hubs within the community to link stakeholders and build social capital. This is particularly pertinent when the social enterprise in question is educationally orientated in its primary mission.

Social Innovation and Sustainability Education

As was noted earlier, when educating potential social innovators or seeking to teach social innovation and entrepreneurship, place-based learning and teaching that is embedded in local contexts is critical [6, 25]. This is extremely pertinent when seeking to educate on environmentally focused social innovations and sustainable development [5], as the local context (as identified above) is crucial in delivering innovative solutions that are *needed* by the community. Further, from an educational perspective, such place-based and experiential processes have clear benefits for learners, particularly those from disadvantaged backgrounds, as they provide real outdoor experiences and enhance sustainability [26]. This allows learners to understand the complexity of sustainability issues, as teachers do not over simplify theoretical/abstract concepts, but rather provide experiential practical learning [7]. This type of embedded learning helps to promote community engagement and encourage connectivity, in a way that empowers learners and teachers alike [27], which can help with sustainability engagement and changing environmental behaviours. The delivery of this type of education through hybrid organisational models that emphasise triple-bottom line (economic, social, environmental) value capture [18], only seeks to strengthen this learning journey.

Based upon the prior literature, this chapter therefore proposes that the delivery of education on environmental social innovation and sustainability by hybrid organisations such as social enterprises, provides a best practice model for sustainability education. The role that social enterprises can play as: anchor institutions in the community, building networks between key stakeholders; community leaders responding to and amplifying bottom-up concerns; and educators supporting learning and promoting understanding of top down sustainability frameworks such as the SDGs, puts them in a unique position to scale environmentally focused social innovations and support local sustainability. This will be explored next through an exemplar case-study of a social enterprise delivering environmentally focused social innovation within an ancient woodland setting in England.

Methodological Approach

Design, Approach and Analysis

The research adopts a single case-study approach to exploring this phenomenon, so as to allow theoretical understanding to be developed in a contextual setting. The approach is what Yin [28] termed an ‘intensive’ case-study, whereby theory is developed through the intensive examination of a singular case. This allows for the exploration of the complex facets of an organisation to understand its nature [29]. Whilst this does not necessarily allow for generalisability, it does allow for theory development as a means to better understand phenomenon [28] (in this case social enterprises delivering environmentally orientated social innovation education and raising awareness on sustainability issues).

All data gathered and analysed was open-source, publicly available data through the case-study organisation's website, social media, UK government websites and third party websites of partner organisations and funders. This secondary data was analysed thematically on an iterative basis so that key themes emerged from the data, relevant to the focus of the research reported in this chapter. This allowed the research to draw inferences about the case-study organisation's approach to sustainability education that were grounded in the data. The analysis revealed three key themes that will be explored further in the discussion, namely: sustainability education; community engagement; and hybrid opportunities.

Further, it should be noted that the author of this chapter is also a trustee of the case-study organisation having been so since 2016, and so was able to also use this experience of five years' operating on the Board of Trustees in order to reflect on the organisation's approach to sustainability education. This insider perspective provided the research with a useful counterbalance to the use of external facing (outsider) data. This reflexive approach to the research allowed the researcher to act as a quasi-insider to the organisation, enabling new insights but also allowing potential researcher bias. As Silverman [30] notes, it's important to set this context here, so as to fully embed the researcher's position in the research and the context that they are researching.

Case-Study Overview

The case-study organisation is an SME-sized social enterprise and registered charity, operating in the East Midlands region of England that was established in the mid-1990's and became a fully-fledged social enterprise in 2002.[2] Operating within ancient woodland, the social enterprise also manages adjacent (new) forests, as well as green spaces in the local community, and has a national reputation for environmental sustainability work. In relation to this, the case-study partners with a local university to develop sustainable construction practices and to promote learning within higher education on environmental sustainability, whilst also owning/managing local social housing. The new forests that they manage are also utilised for sustainable wood, which is sawn, treated and sold in bulk or used to create bespoke furniture and craft items in the onsite workshops. The organisation also offers natural burial services in a bespoke cemetery created in the woodland, where people can be laid to rest in eco-coffins in a natural setting.

The organisation encourages public visitors to the ancient woodland, with designated paths, picnic areas and facilities including bathrooms/toilets available, as well as educational boards around the woodland to educate visitors about the flora and fauna present. The case-study also operates an on-site community café as part of

[2] The organisation is Hill Holt Wood and it has asked to be identified in this research and further information can be found online at https://www.hillholtwood.co.uk/.

this offer, which can also be booked out for weddings and corporate events. Further, the organisation also specialises in a wide-range of environmentally focused education, delivering a number of different education programmes, including: school-level education for children and young people excluded from mainstream education; community outreach education programmes (i.e. coppice crafts); and apprenticeships work, vocational qualifications and support for learners with Special Educational Needs and Disabilities (SEND). The organisation also runs a health programme that is a nature-based therapeutic service, based on the Ecotherapy or Green Care model of wellbeing. It engages individual with physical and/or mental health issues and supports the development of their emotional, cognitive and physical wellbeing through engagement in woodland management, conservation and coppice craft activities. This educational and health offer is central to the work that the case-study does, and this offer is also bolstered by the presence of an ancient Roman villa site adjacent to the ancient woodland.

The case-study is a multi-award winning social enterprise in England that has won several local and national awards in the last 5 years alone. These include awards recognising their work to support Looked After Children (children in the UK care and fostering system); a Royal Forestry award recognising their work in education and learning with young people; and an award recognising their work maintaining a local nature reserve. Locally, their awards have also included recognition of their sustainable construction practices and their role in engaging and supporting their local communities. On this basis it can be argued that as a highly successful and long-lasting social enterprise, the organisation represents an excellent case-study for better understanding best practice in educating people on environmentally focused social innovations and sustainability.

Understanding Hybrid Approaches to Environmentally Focused Social Innovation Education

As was identified in the methodology, the data analysis revealed three key themes: sustainability education, community engagement, and hybrid opportunities. These will now be discussed in turn, with regards to both the data explored[3] and the prior literature. It should also be noted that whilst the Covid-19 pandemic has had a clear impact on the case-study organisation, this has not been focused on in this chapter so as to ensure the focus remains tightly on the central aim of the paper; that is, educating individuals around environmentally focused social innovation.

[3] As the data has been drawn from the organisation's website and other supporting publicly available documentation, it is not cited in the document in order to ensure anonymity.

Community Engagement

The case-study organisation is committed to engaging with its local community, seeking to achieve this in a variety of different ways, including:

- Providing the general public facilities and free access to the woodland all year round
- Providing education, training and employment advice for disadvantaged young people
- Establishing sustainable relationships with local government, charities and representative organisations
- Using local materials and services
- Providing ‘experience’ days and promoting knowledge transfer.

The case-study organisation seeks to achieve these aims through a variety of activities, including through the aforementioned woodland access, but also by delivering contracts for local stakeholders such as government (including the maintenance of publicly owned common areas and highway verges). Whilst this provides income to sustain the organisation, it also provide awareness-raising and brand awareness locally, as well providing employment and training opportunities locally.

The organisation also operates a programme to support and encourage the local community to engage in walks in areas of natural beauty, providing green spaces for community wellbeing and mental health, and operating the community café. The author can also reflect on his experience as a trustee of the organisation over the last five years, in which he has seen the lengths the organisation goes to, in order to engage the local community and ensure that local people from diverse backgrounds are represented through its decision-making structures (i.e. on the Board of Trustees). The organisation also promotes engagement through its social media channels and is helping to lead the community against an (ongoing) proposition for an industrial development in the local area. In this respect we see the organisation acting as a community leader, giving voice to the local community and building social capital to enable further innovation [19, 21].

Sustainability Education

One of the central tenets of the case-study organisation’s work is its educational offer, delivered to young people, people with SEND and also as vocational/community education offerings to adults. This lies at the heart of what the organisation seeks to achieve, with a key sub-aim within its ethos on community engagement being ‘Providing education, training and employment advice for disadvantaged young people’. As was noted earlier, this is done through both statutory education, working with children and young people from the ages of 5–16 years, as well as vocational qualifications for those aged 16 years and over. The organisation also offers nursery support for 2–5 year olds that provides day-care in a woodland environment, helping to focus young minds on nature and sustainability. Further, for adults its education offering extend to team-building days and workshops on sustainable building, as well as engaging with universities and other higher education institutions. In providing these services the organisation is clearly engaged in place-based learning, that can educate around sustainable development [5, 6, 25]. It enables people to feel empowered within their local environment [24] and better understand sustainability needs and what can be achieved locally to enhance environmental sustainability and mitigate against global problems like climate change. Again, here the author can reflect on previous research that he has completed with the organisation which demonstrated the positive impacts that the education programmes delivered to the socially excluded young people engaged [31].

Hybrid Opportunities

The case-study organisation's hybrid model is also a key driver of its local legitimacy, as it is seen as a socially focused, financially sustainable independent organisation that is committed to social and environmental sustainability [13]. Indeed, the social enterprise's third key mission ethos is to 'Run an economically viable social enterprise', with the specific sub-aims of this being:

- Achieving an annual surplus for investment back into the charity and innovation within the business
- Maintaining a diverse range of income streams, clients, products and services
- Manufacturing and selling woodland added-value products
- Ensuring every new venture is sustainable and can continue to benefit the local community and environment
- Funding and providing opportunities for employees' personal and career development.

This financial sustainability, combined with hybrid social and environmental aims, also provides the organisation with independence to pursue activities and programmes of work that it feels will be most beneficial locally (and to maintain the ancient woodland at its core). Indeed, one can argue that it is this (relative) financial independence that allows the organisation to engage in the community engagement activities that it does and to have the impact that it achieves. It is harder to make this argument in relation to educational provision, especially given that large parts of its educational income is for statutory educational provision, but here the organisation seeks to deliver the educational outcomes required by local and national frameworks, whilst blending learning with their unique place-based approach to sustainability. Nevertheless, these hybrid opportunities also include hybrid tensions, and here it is the role of governance frameworks (i.e. oversight from trustees and the Senior Management Team) that help to ensure that the balance between the three financial, social and environmental missions never becomes too uneven.

A Model for Environmentally Focused Social Innovation Education

This chapter has sought to better understand how environmentally focused social innovation can be better delivered and educated. Set within a Weberian framework of empowerment [8] and centred around the prior literature on social innovation and social enterprise, sustainability education, and networks, the author argues that social enterprises can play critical roles as anchor institutions locally and globally in educating people on sustainability whilst enabling/empowering others to become social innovators also. Figure 3.1 below outlines the model developed from this examination of a singular case-study organisation, to demonstrate how and why such social enterprises can deliver these models, and to provide best practice guidance to other scholars and practitioners as to how this can be developed elsewhere.

The model identifies that such organisations operate within the social innovation ecosystem, as a critical network hub for stakeholders, enabling communication and understanding between different groups, and decoding community needs and international frameworks into mutually coherent logics (and translating these to the wider community). In this respect they play the role of governance framework (i.e. the SDGs) decoders [23], whilst also empowering the local community and developing change locally [24]. This enables the scaling of environmentally focused social innovations at the local level, by supporting place-based EFSI [23], and embedding this within community logics. The organisation is able to achieve this because it has legitimacy, emerging from both its hybrid model and its educational offer. In regard to

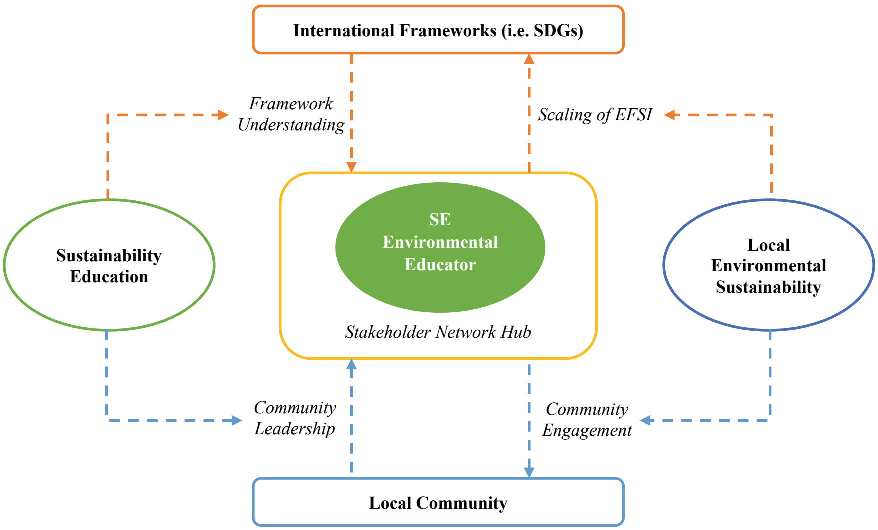

Fig. 3.1 Educating for environmentally focused social innovation (EFSI) best-practice model

the former, the organisation's hybridity offers legitimacy as the organisation is financially self-sufficient but socially orientated [13], meaning that different stakeholder groups retain high levels of trust in the organisation, as its seen as independent but working towards the common good. This trust is also enhanced by the educational role of the organisation, which also aids legitimacy by placing the organisation as a knowledge expert in the field, which is further enhanced through its partnerships and networks with high-trust external educators such as universities. This enables the organisation to decode frameworks such as the SDGs for local communities and young people, by providing real-life, outdoor experiences that allow the complexity of sustainability issues to be understood through experiential learning, learning that empowers the community holistically [7, 26, 27]. In this way the organisation acts as a social innovator in the best possible sense, by enabling social action at the community level and improving the communities' collective resources to deliver this action [8, 9].

Limitations and Further Research

This chapter presents exploratory research, based upon a singular case-study in order to develop theory. Therefore, the results cannot be generalised to a wider population, nor can one argue that this type of environmentally focused social innovation education is limited only to social enterprises (albeit the author suspects that it can only be achieved by truly hybrid organisations). Further research is therefore needed to explore this model in relation to other organisational models, as well as hybrid and social enterprise organisations in England and beyond, in order to test the efficacy of the proposition. However, in providing a theoretical approach on how to deliver sustainable, environmentally focused social innovation education that succeeds at both global and local levels, the author contends that scholars and practitioners could learn much from this case-study example.

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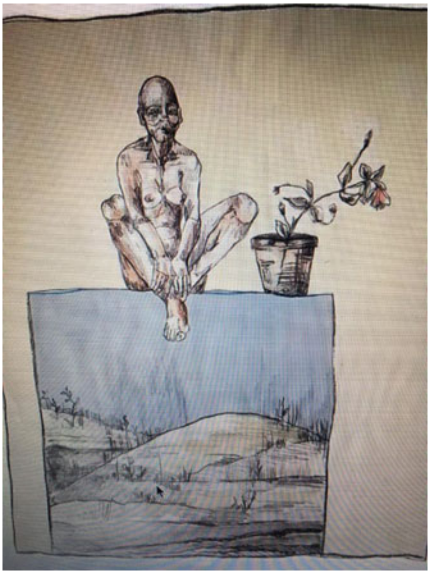
Chapter 4
Environmental Education for Sustainable Development: Working for Fundamental Rights

Maria Luísa Vasconcelos and Clara Vasconcelos



Ilustration: Ana Pinho

Man has always been a poisoner; the beast who soils his own nest. What cultural revolution is needed for him to climb the evolutionary ladder and become a clean animal?
(Saramago, 2019)

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Abstract In this new geologic epoch known as the Anthropocene human activity has entered a vicious circle that prevents sustainable development and hinders human rights. To break this destructive circle a paradigm shift is needed in which profitability, the heart of today's market societies, becomes aligned with sustainable development and intergenerational responsibility. As a result, in this chapter, special attention is paid to the economic pillar of sustainable development, not because of its significance, but because a shift in this dimension is critical, given how market dynamics endanger the ecosystem. Simultaneously, and similarly to other authors, a political-institutional dimension is added to the three traditional sustainable development pillars, indicating that integrated action is required to achieve sustainable development and the SDGs. Some proposals on Environmental Education for sustainable development and intergenerational responsibility are then presented. Firstly, it is proposed that the relationship between Humans and Planet Earth be redefined through Geoethics education in order to prevent an irreversible materialization of the already occurring environmental crisis. Secondly, some intervention strategies for the economic paradigm shift are proposed, including internalizing negative environmental externalities through taxes and tradable permits, promoting eco-innovation, and focusing on the concept of enlightened self-interest. Geoethics, sustainable development, and intergenerational responsibility are ultimately presented as existential imperatives for humanity today.

Keywords Anthropocene · Environmental education · Geoethics · Sustainable development · Intergenerational responsibility · Negative externalities · Eco-innovation · Enlightened self-interest · Sustainable development goals · Human rights

Introduction

Planet Earth is undergoing undeniable climate change, transformations in biodiversity, soils and land erosion, water shortage, poor air quality, in short, a slew of changes that are summoning the disruptive effects on the environment, economy, politics, society, and humanity. According to some authors [1], these times mark the

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beginning of a new geological epoch known as the Anthropocene, which is distinguished by the profound impact that human activity has on the planet. According to those authors, Humans will be a "major geological force for many millennia" while remaining in a scenario "without major catastrophes like an enormous volcanic eruption, an unexpected epidemic, a large-scale nuclear war, an asteroid impact, the new ice age, or continued plundering of Earth's resources by partially still primitive technology (…)" [1]. But what about today's situation of resource depletion and environmental degradation? Today, thirty years after devising a new method of measuring human development, the 2020 Human Development Report recognizes and emphasizes the impact of human activity on shaping the planet, e.g.: climate change, biodiversity degradation, ocean acidification, all highlight the validity of this new geologic epoch, "the Anthropocene, or the Age of Humans" [2].

Note that there is a vicious circle between global imbalances and rising social inequalities. Thus, the only way to prevent hunger, disease, forced population displacements, despair and violence is to take preventive action, breaking the vicious destructive circle through Environmental Education for sustainable development and intergenerational responsibility. There has already been too much irreparable damage and loss inflicted on life, the planet, and fundamental rights. It is critical to Educate in order to redo Man's signature in the Anthropocene.

Following this reasoning, we will begin this analysis with a brief review of the concept of sustainable development and the SDGs of the 2030 Agenda, and propose that a new growth paradigm based on sustainability and environmental responsibility should emerge, or the goals of sustainable development will be extremely difficult, if not impossible, to achieve. The chapter then presents Education as a fundamental human right and Environmental Education as a requirement for achieving sustainable development, and it suggests different lines for a pedagogical intervention. The first proposal focuses on how humans interact with their environment and suggests that it is critical to structurally teach Geoethics through actions that, while segmented, have long-term and cumulative effects on the relationship between Man and planet Earth. A second proposal is concerned with changing the economic growth paradigm and addresses three lines of intervention: (i) internalizing environmental negative externalities; (ii) bringing about eco-innovation by dressing the causes of environmental degradation while also promoting economic advancement; and (iii) relying on enlightened self-interest to address the benefits of a healthy and respectful relationship between the economy and environmental stability, a fundamental and necessary requirement for the fulfillment of human rights.

SDGs and Fundamental Rights—the Need for a Paradigm Shift

In Our Common Future sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [3]. Despite its apparent vagueness, this definition serves as the foundation for a report that makes two critical points: it reconciles economic development with environmental and social sustainability, and it emphasizes the importance of intergenerational equity. It is important to note that sustainability is a property of a system, whereas sustainable development is a dynamic concept that refers to a process involving continuous change and improvement of the quality of life while ensuring the sustaining basis for human well-being.

The definition of environmental and social sustainability would take many years to perfect, and the seventeen SDGs of the 2030 Agenda would clearly demonstrate how intricately intertwined the three qualitative pillars of sustainable development are: the social pillar ("continued satisfaction of basic human needs"), the environmental ("continued productivity and functioning of ecosystems" and "protection of genetic resources and the conservation of biological diversity") and the economic ("the limitations that a sustainable society must place on economic growth") [4].

These three pillars are commonly represented as three intersecting circles with sustainability at the center, or as a concentric circles approach departing from the economic dimension in the center to the environmental dimension on the outskirts, or as three pillars supporting a triangular roof that represents sustainability [5]. It is worth noting that Soromenho-Marques [6] rejects the "equal footing" paradigm, which assigns the same weight to the three sustainability pillars, and instead advocates for the inclusion of a fourth political-institutional pillar. In both cases, we agree with his position, both because of the need to recognize the dynamics of the interaction between the various dimensions of sustainable development, and because a paradigm shift in the direction of sustainability does not appear to be possible, effective or long-lasting without a strong political and institutional foundation. Some authors [7, 8] present a similar argument, adding an institutional pillar to the previous three; however, other conceptualizations, such as the inclusion of a cultural, technical, or technological dimension, could, however, be proposed.

In any case, what is important to recognize here is the existence of a contemporary sustainability centered on the seventeen SDGs of the 2030 Agenda, all of which are explicitly based on the three pillars formula. To this extent, achieving the SDGs is tantamount to a universally applicable plan of action aimed at achieving greater full respect for human rights. This universality and human rights dimension are the most visible distinctions between the SDGs and the Millennium Development Goals (MDGs), because the MDGs were designed specifically to address the obstacles, gaps, and dependencies of developing countries, whereas the SDGs respect all countries equally and are further presented under the pledge to "leave no one behind" [9]. Ultimately, the 2030 Agenda will be successful only if the SDGs are implemented and delivered while keeping fundamental rights in mind, ensuring peace, justice, and equity for all, as explicitly stated in the Declaration of Human Rights (1948).

The seventeen SDGs outlined in the 2030 Agenda are intricately linked, resulting in both synergies (positive interactions), e.g.: producing renewable energy reduces fossil fuel dependency and helps to decrease gas emissions; and in trade-offs (negative interactions that jeopardize progress on other goals), e.g.: using nonrenewable fossil fuels contributes to smog and acid rain, and is directly related to global warming. Furthermore, because profit is at the heart of market societies and will continue to be so in the foreseeable future, the market's geo-ethically ignorant dynamics will continue to influence the social and environmental pillars [10]. In other words, given the need for a shift in the economic growth paradigm that aligns profitability with sustainable development and intergenerational responsibility, the economic pillar should be examined and scrutinized with great care (see Fig. 4.1).

Intergenerational equity, according to Emas [11], is the process of ensuring that resources are effectively preserved for future generations and is "one of the major features that distinguish sustainable development policy from traditional environmental policy, which also seeks to internalize the externalities of environmental degradation" (p. 2). The integration of intergenerational equity concerns into all aspects of decision making—the political-institutional dimension—is a key principle of sustainable development that underpins all dimensions. Accordingly, so as to achieve sustainable development, concerns about the environment, society, and the economy must all be integrated and aligned throughout decision-making processes [11]. Without this new paradigm shift, achieving the SDGs and respecting fundamental rights will be extremely difficult, if not impossible.

In an ideal world, this new growth paradigm would establish a new framework for evaluating company performance beyond the strictly financial dimension. Socially

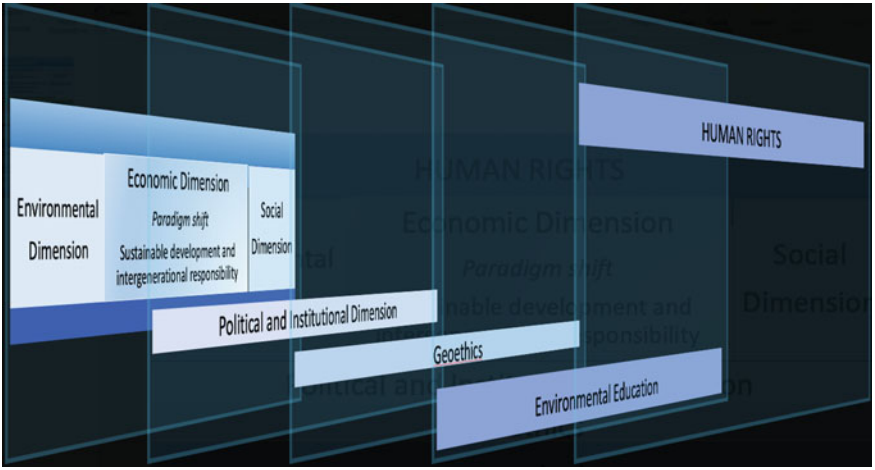


Fig. 4.1 Pillars of sustainable development and intergenerational responsibility

and environmentally conscious investors are currently using Environmental, Social, and (Corporate) Governance Criteria (ESG) to make socially responsible investments (SRI). These ESG criteria assess how well a company takes care of the environment, by examining environmental criteria (e.g.: energy sources, waste and waste disposal, pollution and management of toxic emissions, natural resource conservation, treatment of animals, compliance with government environmental regulations), social criteria (e.g.: relation with suppliers that are not socially and environmentally conscious; healthy working conditions; fair wages; inclusive policies;) and governance criteria (e.g.: ongoing controversies related to workplace discrimination, animal welfare, human rights). Friede [12] identified several opportunities for ESG to outperform the market in his extensive study on ESG and financial performance and highlighted the need to promote responsible long-term investment, aligning the interests of investors with those of society. However, he also emphasized the importance of having a more detailed and in-depth understanding of how to incorporate ESG criteria into investment processes.

Accordingly, we maintain the need to ensure, first and foremost, the geoethical sense of respect for the life of the planet and human rights through education, and, secondly, the need for a paradigm shift toward a model of sustainable development and intergenerational responsibility that incorporates the principle of sustainability in business performance and the growth paradigm.

Educational Proposals

From Theory to Practice

Education is considered a fundamental right (Art. 26°/1 and 2 of the Universal Declaration of Human Rights) and Environmental Education is a prerequisite for achieving sustainable development. In this sense, the United Nation's Decade of Education for Sustainable Development (UNDESD 2005–2014) was an attempt to mobilize and integrate sustainability into national educational strategies and at all levels of government.

Simultaneously, the UNDESD 2005–2014 goals were developed alongside other international initiatives, such as the Millennium Development Goals (MDGs) of 2000 and the Johannesburg World Summit on Sustainable Development (2002).

Furthermore, the 2003 European Declaration on Sustainable Development (EDS) established the framework for the 2005 UNECE Strategy for Education for Sustainable Development, with the main goal of equipping people with the knowledge, competencies, and tools necessary to address sustainable development correctly. This strategy, which was to be implemented in various national legal systems, regarded education as a fundamental human right and a prerequisite for sustainable development due to its ability to promote critical thinking, environmental awareness, and attitude changes [13].

The relevant action plan, as outlined in the UNDESD 2005–2014, focused on four strategic pillars: (a) Quality of Education; (b) Educational Programs; (c) Technical and Professional Training; (d) Public and Media Awareness.

Its implementation required cross-cutting initiatives from very different sectors of civil society (schools, academia, businesses, non-governmental public organizations, media outlets, municipalities, and administrative bodies) to work together and create synergies in order to achieve the goals of sustainable development; e.g.: workshops, lectures, seminars, training and cognitive activities, publications, publishing stamps, school competitions, theater plays, ballet, television and radio programs, online platforms, among others [14]. Results of the concrete activities and actions on the ground were firstly presented in the Review of Contexts and Structures for Education for Sustainable Development (2005–2009), and then in Education For Sustainable Development—An Expert Review of Processes and Learning (2010–2011). It was argued that there was a need to leverage civic-economic, political and social practices compatible with sustainable development and intergenerational responsibility, beginning with schools and progressing to families, communities and various forms of actions of individuals as full citizens. It was also argued that synergies in the performance of various local, regional, national, and international actors, such as the School, the Academy, local authorities, NGOs, media outlets, and other official institutions, should be encouraged.

In 2012, the United Nations Conference on Sustainable Development—or Rio + 20—focused on defining strategic initiatives to achieve sustainable development, including poverty eradication goals, natural resource management, reducing environmental impacts, and increasing environmental efficiency. Similarly, the Millennium Development Goals (MDGs) were adopted, and, later, in 2015, the new Agenda 2030 for Sustainable Development was unveiled, reinforcing the United Nations Environmental Program [15].

Despite all these efforts, it must be acknowledged that the results obtained in light of the proposed objectives are still relatively small. Furthermore, when considering the initiatives developed at the School and Academy levels, the disenchantment is even heightened, as it frustrates the expectation that the younger classes, formally educated at School, will carry their environmental awareness, preventive tools and competences into their families, communities and work lives. What new proposals, then, for environmental education for sustainable development?

Environmental Education for Sustainable Development: Teaching Geo-Ethics

The proposed intervention in Geo-Ethics aims to prevent the irreversible materialization of an environmental crisis, which is already causing devastating economic, social, and human rights consequences. This crisis manifests itself in a variety of ways, including discrimination and precariousness in the lives of millions of people in a variety of locations. Geo-Ethics Education is thus founded on the Ethical environmental principles and values of justice, equity and intergenerational responsibility, which stands as a categorical imperative in the relationship between humans and nature, between man and planet Earth.

As such, we start by accepting the proposal of Soromenho-Marques [6], who suggest five guiding principles for Environmental Education and sustainable development: (1) "To educate for intervening citizenship" promoting new forms of civic participation within the strategic dimension of environmental education; (2) "to educate for a critical approach to development," aiming for continuous improvement; (3) "to educate while taking into account international experience", thus benefiting from the circulation of knowledge; (4) "to educate while integrating the lessons of national experience", building upon successes and setbacks; and (5) "to educate for the promotion of a more cohesive society and a more efficient State", thereby favoring cultural change beyond formal school, extending to civil society and public administration.

Following acceptance of these principles, lines of action for sustainable development must be concretized, cementing the path from theory to practice, from verb to realization. As a result, initiatives addressing issues such as climate change, resource depletion and exhaustion, and globalization contradictions that create Anthropocene-specific imbalances that exacerbate human rights afflictions are required.

This Environmental Education for sustainable development must be based on teaching of (geo)ethics and the values of intergenerational responsibility, transforming individual, irregular and atypical behaviours into transversal, ordinary and collective practices that prioritize the preservation of this "paradise lost". Geoethics was originally developed in the context of geosciences as a rediscovery by geoscientists, but end up becoming a process of raising awareness, increase responsibility and enlightening geoscientists about their cultural and social role [16]. Although it emerged as a deontological need, the maturation of this new field of knowledge has strengthened its theoretical foundations in recent years. Presently, it comprises the relations of humans with the Earth system considering principles and values that can benefit the humankind and geo-ecosystems [17]. Environmental education, which incorporates geoeducation and strengthens geological heritage through holistic approaches and multidisciplinary connections, is expected to play a significant role in promoting geoethics' values [18]. Teaching sustainability and intergenerational responsibility has been a long-delayed Ethical exercise, but it is now a critical existential issue for humanity's future. Geoscientists are urged to promote geoeducation as a fundamental social value in this direction, so that students grow into aware and informed citizens [18, 19].

As a result, an Environmental Education for Sustainable Development curriculum connecting natural and social science contents within the context of sustainable development and addressing geoethics is a critical existential issue, should be developed. It should also include formal, non-formal, and informal teaching methods, integrate several programs across all teaching levels' curricula, and be integrated into the lifelong learning process [20].

The intervention in Schools and Academia should span the entire academic curriculum, beginning in primary school, to gradually make students aware of the full impact of their relationship with the environment, whether individually or collectively. The traditional method of teaching should be supplemented with a strong component of practical and interdisciplinary application of real-life situations involving various sectors of economic activity, allowing for specific training in sustainable behaviors. This training could be repurposed into other training programs for specific professionals from various fields.

Appropriate materials and instruments should be created and implemented, as well as made available also to educators. They should be accessible via multimedia and electronic resources, ensuring their adequacy and wide distribution. At the same time, the efforts and outcomes of environmental and sustainable development research remain critical, and their findings should be integrated into the educational system and shared with the global scientific community [20].

Furthermore, concern for sustainability and intergenerational responsibility should be present in all aspects of public policy decision-making, with special attention paid to Education, Environment, and Economics and Finance. Remember, as previously stated, that for and Environmental Education intervention to be successful, a parallel shift in the growth paradigm is required, in which environmental concerns must coexist with profitability ratios. Indeed, a fragmented approach to environmental, social, and economic goals will jeopardize the pursuit of sustainable development [20].

Changing the Economic Growth Paradigm

The inadequacy of the material dimension and economic indicators to measure sustainable development *de per si* has long been recognized, and other qualitative dimensions, such as those caused by the social and environmental dimensions, have be included. Nonetheless, while economic growth is a "necessary but not sufficient condition" for economic development, this quantitative dimension is inextricably linked and (still) powerful enough to jeopardize the fruits of any given sustainable development strategy. As a result, in order to achieve sustainable development, the market economy's growth paradigm must be altered. Unfortunately, at this point in history, it is still impossible to completely avoid the occurrence of those (negative) externalities. However, they can be reduced or internalized through negotiation or government intervention, sustaining a new environmentally friendly basis for economic growth, supported politically and institutionally on the basis of Environmental Education and Geoethics.

Internalizing Environmental Externalities—Taxes and Tradable Permits

Negative externalities are essentially negative side effects imposed on third parties that are unrelated to the production or consumption of a specific good or service and are not reflected in market prices. Take pollution for example. The air is polluted when factories are producing goods that benefit society in other ways. How much pollution is society willing to accept for those products? Assuming that pollution could be directly observed and controlled, the social optimal level of pollution would be reached when the marginal social benefit (the benefit gained to society associated with one further unit of pollution) equaled the marginal social cost of pollution (the increased cost imposed on society associated with one further unit of pollution). The problem is that a market economy left to its own will not arrive at this solution since those who benefit from pollution polluters have no incentive to compensate for the negative externalities they impose on others, i.e., the polluter has no marginal cost for pollution.

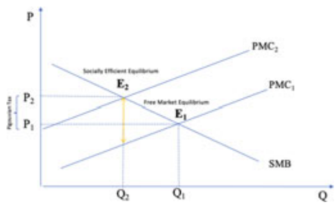
This external cost is best known as an negative environmental externality, which refers to uncompensated environmental consequences of production (and consumption) that have an impact on business costs (and consumer utility) outside of the market process. Negative externalities are defined as market failures caused by individuals or businesses in which private production costs are lower than the social cost involved and are not accounted for in the price of a good or service. What can be done to address these unavoidable and sometimes harmful social costs?

A first suggestion is that negative market failures that accompany economic growth could and should have a financial return. Presently, the main policies to protect environmental pollution, for example, involve taxes and tradable permits.

Accordingly, Pigou [21] proposed that to correct negative externalities a tax on the activities responsible for their production should be levied, at a rate that equals social external costs to private costs to the external costs, the Pigouvian tax. Note that Pigouvian taxes are fairly frequent in today's societies, for example, carbon emission taxes, which ensure that producers of carbon products bear this external cost, and a charge on plastic or even paper bags, which encourages material reuse and discourages deforestation.

According to Pigou (1920), pollution-reduction initiatives should be backed by the polluter in proportion to the extent of societal harm or pollution levels that exceed an acceptable (standard) level—the polluter-pays principle. Polluting the environment would be discouraged in this case because the cost of the negative externality would be passed on to the polluter via the Pigouvian tax (Fig. 4.2).

However, as the Coase theorem demonstrated, if costs of doing business (transaction costs) are sufficiently low, it will always be possible for individual to reach an efficient solution (internalize the externality) without governments' interventions, even in the presence of negative externalities. However, as demonstrated by the Coase theorem, if the costs of doing business (transaction costs) are sufficiently low, it will always be possible to reach an efficient solution (internalize the externality) without government intervention, even in the presence of negative externalities [22].



Under free market conditions, a negative externality would result in equilibrium E_1, at which the social marginal benefit (SMB) equals the private marginal cost (PMC_1), lower than the social marginal cost, due to the additional costs brought about by the negative externality. This is equilibrium (E_1) is inefficient. It will only become socially efficient, at E_2, when the social marginal cost equals the private marginal cost plus the Pigouvian tax, ideally set at a level equal to the costs of the negative externality (E_2: SMC = PMC_2=PMC_1+Tax).

Fig. 4.2 The Pigouvian tax [11]

As such, externalities do not always result in inefficiency since people are motivated to negotiate mutually beneficial transactions, internalizing the externality and making the outcome efficient even without government involvement. However, numerous circumstances may prevent individuals from negotiating efficient deals, such as high communication costs when multiple parties are involved, expensive legal services, and costly bargaining delays. This is the time for government intervention [22]. The key issue is selecting the appropriate level of tax. If the tax is set too low, the environment will not improve much, and if it is set too high, result will be inefficient.

Although this uncertainty cannot be avoided, a different technique can be employed by using tradable emissions permits. According to this alternative, the government establishes a market-based solution to correct negative production externalities. To begin with, the government issues and sells companies permits giving them legal permission to pollute a particular (limited) amount for a set period of time. If a company pollutes less than its permits allow, it can sell its unused quota to another company that pollutes more, and vice versa. Credits are traded in designated zones. On the one hand, tradable pollution permits eliminate the need to calculate the direct social cost of pollution. On the other hand, there is no agreement on the effects of tradable permits on pollution, with some academics claiming that they increase pollution and others claiming benefits or ambiguous outcomes.

It should be noted that some environmental organizations have been known to purchase pollution permits in order to obtain clean air. It's a practical solution, but it can't be viewed as a structural one. This approach has been applied to many different types of resources such as air pollution control, fisheries management, water resources and water pollution, land use control—see Colby's prior survey [23] related to tradable permit systems in different resource contexts.

Bring about innovation and profit

A second suggestion regarding the possible approach to the unavoidable negative eco-system externalities that result from the economic growth model of market societies, is to recognize that efforts to protect the environment may also stimulate innovation and in some cases bring about profit. According to Porter and van der Linde "by stimulating innovation, strict environmental regulations can actually enhance competitiveness" [24] creating win–win situations for the environment and the economy. Nonetheless, tests to this theory have been inconclusive [11].

This new challenge is known as eco-innovation, and it refers to new technologies, processes, products or services that have the potential to significantly advance the goals of sustainable development, especially in terms of "enhancing nature's resilience to environmental pressures, or achieving a more efficient and responsible use of natural resources" [25]. Eco-innovation is also viewed as a business opportunity because it promotes eco-efficiency, optimizes the use of resources, and strengthens the corporate image as environmentally friendly.

Accordingly, the empirical findings of Costantini and collaborators [26] show that the direct and indirect impacts of eco-innovation vary across the value chain and depend on the technology used and the type of pollutant under consideration; as a result, companies should adapt eco-innovation technologies, products, and services along the supply chain in a coordinated and strategic manner, ensuring environmental sustainability.

Enlightened self-interest

The concept of enlightened self-interest was first introduced by the political scientist Alexis de Tocqueville (1805–1859) to refer to the advantage of the individual working for the good of all. Today, this concept is also used to refer to the relationship between the economy and environmental stability [27], and it encourages businesses to reduce the environmental impact of their operations. Accordingly, like Porter's win–win hypothesis, the enlightened self-interest approach rejects the trade-off between the environment and the economy and instead asserts that sustainable development policies can address the causes of environmental degradation while also promoting economic advancement [11, 24].

There can be no sustainable development without environmental protection, especially given the extent of damage already done to the ecosystem, such as climate change, deforestation, water scarcity, unsustainable mining, and CO_2 emissions from the burning of fossil fuels and plastics in the oceans, amongst others. To have an enlightened self-interest behavior implies practicing pro-environmental behaviors, which can be business complex and demanding, as well as simple and routine activities such as taking public transportation, carpooling, practicing sustainable mining, reducing gas emissions, recycling, and reducing water and electricity use at home. Simultaneously, public awareness and mobilization are required, not only through schools and families, but also through non-governmental organizations and social media, which should be encouraged to debate issues concerning sustainable development.

Conclusions

Human activity is depleting resources and degrading the environment on Earth, ushering in a new geologic epoch known as the Anthropocene. Accordingly, global imbalances and rising social inequalities caused by human activity have entered a vicious circle, preventing sustainable development and hindering human rights. The only way to break the destructive circle is through Environmental Education for sustainable development and intergenerational responsibility.

To begin with, a new growth paradigm based on sustainability and environmental responsibility must emerge; otherwise, it will be impossible to achieve the goals of sustainable development. This paradigm shift has to align profitability with sustainable development and intergenerational responsibility, and thus the economic pillar must be examined and scrutinized with great care.

This is not to say that the economic pillar of sustainable development is more important than the social and environmental pillars; quite the contrary, the economy must serve people and nature rather than the other way around. Since sustainability and intergenerational responsibility concerns are to be are to core of all decision making a political-institutional dimension has been added to the three pillars, indicating that an integrated action is needed in order to achieve sustainable development achieve the SDGs.

Accordingly, the lines for a pedagogical intervention to be used Environmental Education are as follows: firstly, teaching geoethics, so as to re-educate the relationship between Humans and Planet Earth and, if possible, reverse the environmental crisis that is already wreaking havoc on the economy, society, and human rights; and secondly, changing the economic growth paradigm, without which resources will continue to be depleted, and the ecosystem will be irreversibly damaged. Some lines of intervention for this paradigm shift may include the following: internalizing negative environmental externalities through taxes and tradable permits, promoting eco-innovation and thus creating win–win situations for the environment and the economy, and building on the concept of enlightened self-interest and making the importance of pro-environmental behaviors understood.

Respect for the Earth, the pursuit of human rights, and the ongoing search for humanity should be enough to justify a new relationship with the environment. If they are not, let us keep in mind that geoethics, sustainable development, and intergenerational responsibility have all become existential imperatives for humankind today.

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Chapter 5
Nature as a Teaching Resource and the Nature of Learning

Nir Orion

Abstract This chapter is an integration of the author's previous publications. It rearranges previous findings and ideas to reconstruct the essence of environmental education with the meaning of Nature. This manuscript distinct between the nature of learning, the natural Earth, and the outdoors as a powerful teaching resource and integrates them. However, these are not two separated views; instead, they reflect the same phenomenon (education) from different angles. These two perspectives were already connected to serve the basis for the Earth systems education approach. The main message of this manuscript is that environmental education should adopt the earth systems education approach.

Keywords Environmental education · Earth systems education approach · The instinct of learning · The outdoor learning environment · Essentialism

> Environmental education is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution (Stapp, 1969)

Introduction

This manuscript is a chapter in a book entitled "Enhancing Environmental Education Through Nature-Based Solutions." Thus, this book deals with very broad and multidimensional and, to some extent, even controversial concepts like environment, education, environmental education~~,~~ and nature. For example, the term "Nature" refers to the Earth's components such as wild animals, wild plants, rocks, and forces and processes that happen or exist on Earth independently of humans. But, in terms of physical life, "Nature" refers to forces and processes responsible for the life of all living beings, including humans. Moreover, it also refers to a person's physical and emotional character or the characteristics a person is born with.

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Environmental education, like any education, is about the interaction between people. Education in schools involves the interaction of an adult (teacher) with youngsters (students). This interaction includes two supposedly parallel processes: Teaching and Learning. However, learning is an instinct - a natural process. Therefore, the ability to enhance environmental education (and any other type of education) requires, first and foremost, understanding the nature of learning.

The chapter is based on previous articles [1–3]. It rearranges previous findings and ideas to reconstruct the essence of environmental education with the meaning of Nature. It starts with the nature of learning and then presents the **E**arth systems as a powerful educational approach for developing environmental insight, which is the ultimate goal of environmental education.

The Nature of Learning and the Essentialist Paradigm

Learning is a natural process—it is an instinct. Like any instinct, the urge to learn is only called into play by a stimulus or a need. The inborn abilities to learn and teach are not the exclusive domain of the human species; they are also naturally inherent in animals. For example, the lioness and her cubs have innate characteristics that allow them to teach and learn how to hunt for prey. The learning mechanism in humans, as in other animals, is instinctive and therefore occurs in response to stimulation. Possibly, the difference between humans and other species lies in the relationship between learning and the characteristics of the natural and intrinsic motivation for learning. For humans, learning has evolved far beyond the basic existential survival; it also serves humans' natural curiosity and inborn tendency to seek novelty and challenges. Thus, as already noted, in humans, the central stimulus for learning is emotional, and cognition follows this emotional need.

However, there is a built-in contradiction between learning instinct and the essentialist educational philosophy most schools in most countries preserve and support. Essentialism has been the dominant education approach in public schools worldwide since their foundation in the eighteenth century. This socio-economic approach sees the child as raw material and the school as the means to mold the child into an obedient and productive citizen. Therefore, Essentialism ignores the element of personal relevance. Students, as individuals, must accept and perform whatever the authorities have decided that they should learn, regardless of how relevant they find it for their present-day life [4].

Since the Essentialist paradigm contradicts the instincts of learning, the traditional Essentialist teaching approach is based on suppression of the learning instinct. Namely, the government, rulers, OECD (Organization for Economic Co-operation and Development), etc., decide what students should "learn," but for many students, there is a discrepancy between what was decided for them and what interests them. Education systems everywhere focus on the needs of the society, nation, and economy, among others. They know how to transform these needs into syllabuses, curricula, guidelines, textbooks, standards, national tests, and international tests.

Therefore, they prefer to stick to the traditional Essentialism model, which is much cheaper, mainly because it maintains social hierarchies.

Unfortunately, the traditional classroom stifles this natural instinct, consequently encouraging boredom, absenteeism, rebellion, and the intrinsic motivation for learning among many students worldwide. This gap between the natural instinct of learning and the traditional schooling approach is a central reason for the worldwide phenomenon of children's reluctance to attend and struggle to learn in schools. Children must find their own meaning and relevance in what they learn in school since this sense of relevance is likely to stimulate their interest in the subject matter, this tapping into their learning instinct.

Environmental Education, Nature and the Earth Systems Approach

Education has been acknowledged, by both researchers and policymakers, as a key to managing humanity's current environmental crisis. But, before connecting environmental education with the nature of learning, it is essential to focus on the connection of environmental education with physical nature.

Environmental educators worldwide recognize their scope of work through a definition crafted in a 1969 conference in Tbilisi, Russia by Stapp [5] considering that environmental education aims to create citizens who are knowledgeable about the biophysical environment and its challenges, aware of how to help solve them, and motivated to work toward their resolution.

One of the goals that have been set for environmental education is the development of environmental literacy. The term environmental literacy was coined by Roth [6], who defined it as 'understanding how environmental knowledge and learning skills impact the connection between humans and their environment. Later he expanded the term, claiming that environmental awareness and learning skills, in addition to environmental knowledge, would allow those with environmental literacy to act and participate in solving environmental problems. Though the precise definition of this literacy has remained somewhat ambiguous, the shift from 'understanding the connection' to 'solving environmental problems' reflects that the emphasis of environmental literacy shifted to actual environmental behavior and not just on knowledge of the subject [7]. However, since then, 'environmental literacy' became a problematic concept because many people have defined it, over the years, in different ways. During a lively academic-environmental dialogue, the term environmental literacy has been diversely defined [7–14]. Orr [8] referred to the term 'ecologic literacy' and claimed that if a particular individual understands a wide range of ecological-environmental problems, he or she can project this understanding onto their daily environmental behavior. Weelie [15] added that a person would develop environmental awareness only after understanding the science behind environmental terms.

In contrast, Thomas, McGarty, and Mavor [16] emphasized the value of beliefs and emotions. McBeth and Volk [17] reviewed the various definitions of environmental literacy. They found two features common to most of them: (a) it is defined and measured according to knowledge, attitudes, and environmental behavior (Tbilisi Declaration), and (b) it refers to three primary subjects: nature, environmental problems, and sustainable solutions. Nevertheless, despite these commonalities, a long and extensive review of the term 'environmental literacy' still does not yield a significant correlation among the concept's three components (knowledge, attitudes, and behavior). These three measures are interconnected in the various definitions, so that knowledge impacts attitudes, which influence behavior [11, 18].

However, many studies conducted over the past few decades indicated low levels of environmental literacy amongst primary school, high school, and college students. They also did not find a significant correlation between their subjects' environmental knowledge and attitudes on the one hand and their behavior on the other. Some studies also showed that the only behavioral changes connected to environmental knowledge were recycling and reduced resource use [19–25].

Orion and Libarkin [26] suggested that the failure of the traditional environmental movement to change the environmental behavior of citizens worldwide is derived from its focus on the development of environmental awareness instead of focusing on environmental insight [27–29]. Environmental insight is composed of three central components: (1) the understanding that we live in a cycling world that is built upon a series of subsystems (geosphere, hydrosphere, biosphere, and atmosphere) that interact through an exchange of energy and materials; (2) the understanding that people are a part of nature, and thus must act in harmony with its 'laws' of cycling; and (3) the study of the interacting Earth systems—within the dimension of deep time and the large spatial scale of geological processes enable students to appreciate the real influence of humans on the Earth in deep time perception.

Understanding the realistic role of the human species on Earth should move society away from the traditional altruistic environmental awareness approach towards the environmental insight (egocentric and geocentric) approach.

Thus, since the essence of Environmental education is the interrelationships between humans and the social world with the physical nature of Earth, the only way to do it is through Earth Systems Education Approach (ESEA).

Earth systems approach is the opposite of the traditional approach to teaching adopted in schools and universities. This traditional way mainly focuses on transmitting information from teachers to students, who must memorize it and give it back through a one-time event called an 'examination.' In contrast, the Earth systems approach is based on the construction of knowledge by learners through the teacher's mediation. Furthermore, the ESEA is based on a close engagement of the learner in the learning process through inquiry-based learning in small groups both in the indoor and outdoor learning environments (Table 5.1).

The shift from traditional teaching to the ESEA requires, among other things, the understanding that learning is a natural process—it is an instinct. The Earth systems education approach has great potential to stimulate students' learning instinct by

Table 5.1 Comparison between traditional science teaching and earth systems teaching

Traditional science teaching	Earth systems teaching
The main purpose is to prepare society's future scientists	The main purpose is to prepare society's future citizens
Discipline-centered teaching (reductionism)	Multidisciplinary teaching
Learning is a mechanical process (essentialism)	Learning is an emotional–social process (instinct of learning)
Teacher-centered teaching (essentialism)	Student-centered teaching (instinct of learning)
Content-based teaching	Integration of skills within contents
The teacher is a source of knowledge/information	The teacher is a mediator for triggering the learning instinct
"Chalk and talk" or PowerPoint prese ntation-based teaching	Inquiry-based teaching
Almost ignoring the outdoor learning environment	The outdoor learning environment is essential and central
School-based learning	Multiple learning environments: classroom, laboratory, outdoors, and computer
Teaching that is derived from the scientific world	Authentic-based teaching that is derived from the real world
Traditional assessment	Alternative assessment

helping them see the relevance of what they learn in their own daily life. This statement is based on the Earth systems content and the existing Earth Science Education (ESE) research, highlighting the central role of the outdoor learning environment in creating personal relevance. This personal relevance should stimulate the learning instinct mechanism and, once this instinct is active, students will cooperate and engage in inquiry-based learning. Consequently, with the right program, students can develop high-order thinking skills, such as the ability to discern between an observation, a conclusion, and an assumption, to think in a geological time dimension (deep time), and to engage in spatial thinking, three-dimensional thinking and system thinking [3].

The Outdoors as the Nature-Based Solutions for Environmental Education

The declared ultimate goal of public education is to introduce and prepare children—the world's future citizens—to the world they live in, on all its components: the natural world, the social world, the spiritual world, and the emotional world. However, while part of the world's social and spiritual, and emotional components might be found even within schools' environment, the physical world is located out of the school.

The essence of the environmental issues is the interrelationships between human society the natural earth systems. Since the natural earth systems exist out of school buildings, a central component of any environmental education program should be a direct interaction with the natural earth systems.

However, integrating the outdoor learning environment within the learning sequence required specific pedagogical knowledge, experience, and detailed and accurate planning.

Orion's [30, 31] spiral learning model for integrating the outdoors as an integral and indispensable component of the teaching sequence involves an inquiry-based learning/teaching sequence. The sequence begins with preparation in the classroom, moves outdoors for firsthand experiences, and then returns to the school for an inquiry-based summarizing unit.

A series of about ten independent studies explored students' cognitive and social outcomes who participated in earth systems-based units that were developed following Orion's holistic model. All these studies highlighted, without exception, the central role of outdoor learning events in the development of cognitive high order learning skills and social wellness. The holistic model served as a conceptual anchor for students to link to the content learned in the classroom and create a concrete relevant framework for constructing higher-order thinking skills. Moreover, all of the cognitive studies highlighted the role of outdoor learning events in encouraging learners to cooperate and engage in inquiry-based learning [3]. The development of thinking processes and social wellness and the connections between students and their physical (natural and non-natural) environment need to be considered simultaneously. The relationship with the immediate environment begins with authentic questions that directly or through the teacher's mediation might enhance students' interest and curiosity and, consequently, stimulate the learning instinct.

Conclusions

It is suggested that the most effective way to enhance environmental education through nature-based solutions is to base environmental education on the nature of learning and the nature of Earth. However, since the earth Systems Education Approach has already done it, environmental education should adopt the ESEA.

The Earth systems content and the existing ESE research highlight the central role of the outdoor learning environment in creating personal relevance. This personal relevance should stimulate the learning instinct mechanism and, once this instinct is active, students will cooperate and engage in inquiry-based learning. Consequently, with the right program, students can develop high-order thinking skills, such as the ability to discern between an observation, a conclusion, and an assumption, think in the deep time dimension, and engage in spatial thinking, three-dimensional thinking, and system thinking.

Unfortunately, essentialism and reductionism control and dominate schools in most countries, as they have done since establishing public schools in the eighteenth century. Under this oppressive conservative regime, the earth systems education approach can only survive in small niches. Therefore, any real effort to change the direction of environmental education towards the earth systems education approach should simultaneously involves the adaptation of progressive education elements. Without such a profound change, environmental education could not reach far beyond the recycling and cleaning of the schoolyard.

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Part II
Environmental Education and its Teaching

Chapter 6
The Importance of Nature-Based Solutions to Enhance Cabo Verde's Environment

Jorge L. B. Neves, Vanézia Rocha, and Diara Kady Rocha

Abstract Cabo Verde (CV) is a small island developing state with many challenges, mainly societal ones based on the natural environment. Despite some advances, environmental sustainability is among the lowest according to the World Bank's analysis. Environmental vulnerabilities become even more intensified with climate change, according to the Intergovernmental Panel on Climate Change, where the natural resource-based economy and tourism are harder to recover. Furthermore, the preservation and management of ecosystems have been deficient, putting pressure on environmental services such as food, environmental quality, biodiversity, and water security. This chapter suggests that the best approach for CV to meet some challenges of the past, present, and future and achieve the Sustainable Development Goals will be through Nature-based solutions (NbS) to complement technological solutions. NbS, such as, Protection of Wild Genetic Resources, Forest Landscape Restoration (FLR), Ecosystem-based Adaptation (EbA), Ecosystem protection approaches (EPA), Marine Protected Areas (MPAs), and Ecological Engineering Forest (EE), will lead to the improvement of fundamental pillars in the sustainable development of CV not only based on monitoring, surveillance and awareness activities, but fundamentally by actions to achieve co-benefits (Natural Environment and Human Well-Being) in which actions are based on education and scientific development.

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Introduction

Cabo Verde (CV) is the southernmost archipelago of Macaronesia, located in the North Atlantic Ocean, between latitudes 14°45'–17°10' N and longitudes 22°40'–25°20' W. The archipelago of volcanic origin includes ten major islands (i.e. Santo Antão, São Vicente, Santa Luzia, São Nicolau, Sal, Boa Vista, Maio, Santiago, Fogo and Brava), and several islets, and this account for a total land area of 4,033 km^2, that is, less than 1% of its total territory [1]. About 99% of the territory is the sea. CV is highly vulnerable to climate change and natural disasters due to its geographical features and mid-Atlantic location. These climate events include frequent droughts, periodic heavy rains, sea-level rise, extreme storms, and volcanic eruptions [2]. Despite the predicted rapid increase in climate change, data show that CV has always suffered from various environmental hazards. For example, the severe droughts of 1975 caused widespread famine, and more recently (2014 and 2017) caused the loss of a large amount of crop, and thus put food security at risk [2, 3]. In addition, volcanic eruption also brings the threat of population displacement and air pollution problems. Therefore, CV is considered a vulnerable country to climate change and where the risks will be worst. According to the World Risk Report 2016, CV ranks 140st out of 171 countries susceptible to natural disasters [4]. The country was considered very vulnerable in the global index of exposure and adaptive capacity to the adverse effects of climate change (CC), with classification in 117th place [2, 5].

Cabo Verde belongs to the Small Island Developing States (SIDS). SIDS are, in general, particularly vulnerable to climate change impacts [6–8]. Compared to other SIDS countries, such as Mauritius, St. Lucia, and Seychelles, Cabo Verde's ranking is much lower, i.e., low capacity to recover from natural shocks, especially for families living in marginal regions [2]. The economy is based on tourism, but at the same time, tourism in CV is established on the natural environment, biodiversity, and food quality. Therefore, it is essential to preserve the resource base on which tourism and most Cabo Verdean families depend.

Preservation and management of the environment are a challenge, so it ranks a modest 78th out of 141 countries in "enforcement of environmental regulations." For example, marine biodiversity is vast and is considered one of the 11 most threatened marine biodiversity "hotspots" globally. CV is an important nesting site for several endangered sea turtles (e.g., *Caretta caretta*), 22 species of dolphins, and whales. In addition, the quality of the natural environment is also threatened by overfishing, various forms of pollution (e.g., solid waste), unregulated extraction of coastal sand for construction purposes, and irresponsible hotel and residential construction near the beaches [2, 9]. Thus, CV's environment offers bird watching, hiking, and trekking in rich hill ecosystems, volcano exploration, one of the top three sea turtle nesting sites in the world, coral reefs for snorkeling and diving, water sports (including sailing, yachting, wind and kite surfing), and sport fishing [2]. But, the development of environmental action plans and the enforcement of regulations are still inadequate, especially in services and values that are mainly dependent on the environment, such as agriculture, fisheries, and tourism. On the other hand, there is no response to other challenges, notably climate change, which will aggravate the country's societal challenges.

To address societal challenges, CV has been elaborating management tools, such as the (i) "Strategic Plan for Sustainable Development of Cabo Verde 2017–2021", which highlights the development of a tourism sector builds on the national environment, culture, and history; and (ii) the "National Biodiversity Strategy and Action Plan 2014 - 2030".

In response, Nature-based solutions (NbS) have been highlighted to face climate change, food security, and sustainable development [10, 11]. IUCN defines NbS as 'actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits' [11, 12] and adopted by 1,300+ IUCN State and Non-Governmental Organizations (NGOs) Members. This definition underlines 'protection, restoration and sustainable management of the world's ecosystems' as central to addressing both the causes and consequences of climate change [11–13].

This chapter discusses the importance of NbS to face societal challenges, mostly food security, environmental degradation, biodiversity loss, water availability, and quality in global environmental change. On the other hand, it is important to realize the gap between environmental management and the mitigation measures applied and how environmental education has been underestimated as a reasonable solution for sustainable development. It is expected that this discussion will be helpful for

CV to bet on NbS as action measures, based on science as decision arguments, and education as prevention and vision for the future. Environmental management must go beyond awareness, monitoring, and surveillance activities, especially in the face of climate change threats in a lack of database, low financial funding, and little scientific research.

Nature-Based Solutions for Food Security

Food Security Through Terrestrial Ecosystems

Generally restricted to soils, plants, water, and the ocean, these natural resources raise a paradigmatic interdependence and of course its sustainable use and conservation [1]. As part of the Sahel region, the islands are influenced by northeast trade winds, with an arid to semi-arid climate, presenting an extensive dry season where the precipitation is very variable (rarely exceeds 700 mm) [14]. Consequently, the archipelago history has been marked by alternating periods of heavy rains and severe droughts, the latter threatening the country's food security (key pillars: availability, access, stability, and utilization [15, 16]) through several famines' periods (e.g., the 1920s, 1940s, and 1970s) decimating thousands of inhabitants [17].

The geography and climate of CV are, in some ways, a challenge for the practice of agriculture. The agricultural population exceeds 30% of Cabo Verde's inhabitants, with agriculture area ca. 44,531 ha, and rainfed and irrigated agriculture dominating the farmer system [14]. The top agricultural commodities in the archipelago are sugarcane, tomatoes, pulses, maize, cassava, and coconuts. Indeed, sugarcane is the most remarkable irrigated crop, particularly its by-product "*grog*" [14]. However, the agricultural sector depends mostly (more than 80%) on rainfall, with maize and beans as the dietary basis in the archipelago [14].

Nevertheless, with recurrent droughts in these islands, this staple food production has been decreased and gradually replaced by imported foods (e.g., rice) [18, 19]. This scenario has negatively affected the families' food security and livelihood, with lower consumption of calories, proteins, and nutrients needed to maintain the dietary food balance and the need to spend more to purchase food [18]. On the other hand, poor land management, agricultural practices, and the use of arable agricultural irrigated areas to limited crops cultivations (e.g., sugarcane) have also contributed to the agricultural unsustainability in the country.

Although the climatic conditions of the islands are adverse and an excellent challenge for agriculture, over the years, some policies and actions have been implemented to make Cabo Verde's agriculture more resilient. For example, some programs linked to adaptation to climate change, namely "National Program of Action for Adaptation to Climate Change" (NAPA 2008–2012) and "National Program of Action to Combat Desertification and Mitigate the Effects of Drought" (PAN/LCD–2015). Also, strategies to ensure food safety, namely ensuring availability and stability of food supply in local markets, or even linked to water availability for agriculture [20]. A recent study [21] demonstrated that CV, as part of the "Economic Community of West African States" (ECOWAS), is one of the best performing countries within the "Comprehensive Africa Agriculture Development Program" (CAADP). Moreover, the Sustainable Development Goals (SDGs) related to agriculture (i.e., SDG 1, SDG 2, SDG 12, and SDG 17) are higher in the archipelago than in the other West African countries [21]. However, much needs to be done to reach zero hunger by 2025, especially when high food imports and investments in agriculture and productivity itself are still insufficient to meet internal needs [21]. In this sense, Cabo Verde must adopt natural solutions to ensure the country's food and nutritious security in the long term. This is crucial when agriculture is heavily rainfed, and food ingresses can be threatened with humanitarian situations, as is the case with the Covid-19 pandemic. NbS to enhance food security could be (1) the protection of wild genetic resources (animals and plants), (2) the management of wild species, (3) the provision of water for irrigation, and (3) the sustainable management of lands [22]. Thus, species adapted to extreme habitat conditions (e.g., drought and poor soil) is suggested as a source for the maintenance of genetic diversity and improvement of the agricultural sector and all the associated biodiversity [23, 24]. Some of the species are Crop Wild Relatives (CWR), the wild taxa genetically related to crops, that constitute an essential source of abiotic and biotic advantage traits necessary for agricultural improvement [25].

In the last years, studies performing the plant genetic resources in CV have revealed an essential diversity of CWR species occurring under extreme conditions that are well adapted to arid lands and poor soils [18]. Some examples are the wild relatives in sugar beet [26], in Brassicaceae [27], and related to the West African millets [28]. These studies have highlighted the predominance of agrobiodiversity hotspots related to adaptation to abiotic stress, namely drought and salinity, and presumably more resilient to climate change. Therefore, as an NbS, these CWR can improve crops against heat and pest-resistant, helping farmers maintain productivity alongside a framework of rising temperatures, increasing water scarcity, and emerging pests and diseases [29]. Additionally, the improvement of local resources by governmental institutions and local farmers through the potential crop enhancement for dryness resilience, promotion of alternative food sources, and improvement of agricultural practices may address the SDG Goal 2 meeting zero hunger [30].

However, the country must move forward in this new path and seek efforts to ensure that the local resources, resilient to the adverse conditions of the country (e.g., drought), are protected and valorized. Internationally, the maintenance of genetic diversity has seen some progress, mainly since the Convention on Biological Diversity [31]. Nevertheless, more work is still necessary to improve biodiversity, especially when the agricultural sector remains poorly sustainable, mainly in developing countries [32].

Food Security Through Coastal and Marine Ecosystems

Food security in the seafood context also involves affordable, safe, and appropriate food for all. It is one of the world's leading challenges today, especially in developing countries [33, 34]. In CV, poverty and extreme poverty continue to threaten sustainable development. About 40% of the population is poor, with 10% living in extreme poverty. The tourism sector has been instrumental in strengthening the economy in recent years. But food security and the lack of accepted international food handling and safety certificates for the country's products means that hotels import most of their food needs, mainly fresh fish, fruits, and vegetables. Moreover, CV ranks 96th considering the subcriteria on health and hygiene [2]. Therefore, the country remains very vulnerable to food quality even with a high level of imports.

CV will be one of the hardest hits by CC. First, CV faces the challenges of excessive rainfall and flooding after long periods of drought, weather events, rising temperatures and seawater temperatures, ocean acidification, salt-water intrusion, and sea-level rise, degradation of coral reefs, coastal erosion, and poor access to safe drinking water. Second, climate variation also affects the economy and society, such as food security, health and tourism, well-being, and livelihoods [7]. Third, there are other challenges such as small land area, isolation, sensitive ecosystems, and limited natural resources. In addition, CV has a fragile economy with high import costs, heavy dependence on external aid, emigration of the active population, and insufficient resources to combat climate change impacts.

On the other hand, anthropogenic pressures, such as over-exploitation, over-harvesting, pollution, and degradation, have been causing new challenges to natural resources, especially marine ecosystems [7, 8]. Thus, climate change represents an increase in poverty, social inequality and puts sustainable development at risk. Also, overfishing has been changed marine biodiversity, and more local fishers must move further away from the coastal zone to fish what they once found closer. This jeopardizes food security, also the safety of fishermen who venture into the open sea with inappropriate navigation conditions.

Most of the Cabo Verdean population eats fish and others seafood. Fish has nutritional value as a source of essential micronutrients (e.g., iron, iodine, calcium, and vitamins A and B), which are not found in other staple foods such as maize, cassava, and rice [35, 36]. Therefore, fisheries policymakers and managers must find solutions to minimize fish scarcity and increase seafood quality in general. Aquaculture was present into the CV Nationally Determined Contribution (NDC) at the UN Framework Convention on Climate Change (Paris, 2015) as one of the possible solutions to improving quality and increase the capture of fisheries [37]. But the total output from the aquaculture sector in West Africa has contributed only about 2% of the total fish supply.

Moreover, aquaculture has been growing slowly, and in West Africa, for example, in Nigeria, the sector only contributed about 0.01% of the national catch [38–40]. As such, aquaculture cannot be considered a viable alternative source of fish in the short term. This is particularly relevant in CV, where there is still a lack of robust scientific studies. Nevertheless, infrastructure is starting to implement the first tuna aquaculture project (see: Atlantic Bluefin Tuna [41]).

Solutions to these problems must be on a broad spectrum, including, for example, adapting food systems to environmental and climate change, understanding food security, and ecosystem awareness. For example, several projections have shown that there could be a substantial reduction in marine fish production, changes in physiology, distribution, and ecology of several marine species in the West Africa region by 2050 [42–44]; to this factor can be added the expected decline in the agricultural sector [45].

Cabo Verde's development priorities are reflected through transformation and growth in key economic sectors, namely the Green Economy and the Blue Economy [46]. However, food insecurity and various forms of malnutrition threaten CV's progress, as data and initiatives show that the country is far from achieving sustainable development goals, namely SDG 2.1 and 2.2. One of the continent-wide transition pillars is the Blue Economic referred to in the African Union's "Agenda 2063 - The Africa We Want" program [47, 48]. The FAO editions (2014 and 2015), as well as the assistance provided by the African Development Bank in 2017, were aimed at supporting the "Blue Growth Charter" [49] in adapting better governance for the aquatic sectors related to food security and the transformation of fisheries production systems [46, 47].

Therefore, NbS is a powerful tool in improving food security. Solutions include, for example, wild species management and protection of genetic resources (especially fish and other marine species). CV has developed the projects to respond to shoreline changes through coastal zone management and does not explicitly mention seafood security. But recently, many delegates from across Africa have supported Ecosystem-based Adaptation (EbA) approaches to Food Security [50, 51]. EbA integrates the sustainable use of biodiversity and ecosystem services in an approach that builds resilience [52].

CV can get the best out of implementing EbA, but there must be a focus on science and local knowledge. Unfortunately, scientific knowledge is little used in policy decisions [53], and this undermines decisions and implementations of NbS while favoring unsustainable engineering-based solutions. EbA has been applied in many SIDSs and with encouraging results. EbA is an approach that integrates the sustainable use of biodiversity to address food security challenges in a strategy that enables adaptation to climate change [50, 54–56]. Fish, for example, is an essential source of protein, but due to overfishing, changes in the seas, and habitat destruction, many fish stocks are declining. EbA is fundamental to terrestrial and marine ecosystems and is linked to physical, psychological, and cultural health services, for example, in the Pacific Ocean cities [50, 57].

Nature-Based Solutions for Environmental Degradation and Biodiversity Loss

Overcoming Environmental Degradation and Biodiversity Loss in Terrestrial Ecosystems

In the past decades, Cabo Verdean policymakers and stakeholders have performed some actions to reduce the direct pressure on biodiversity and the environment. For example, the prioritization in mitigating the island's desertification and the adverse effects of prolonged droughts, namely through reforestation strategies. Also, conservation actions are directly related to the unique fauna and flora of the archipelago through protected areas [53, 58]. However, these actions always need to be carefully addressed since biodiversity, namely terrestrial flora and marine fauna, is based on the Cabo Verdean livelihood.

Forests are vital for the sustainability of the planet. Covering ca. 31% of the world's surface area, it is home to a large part of its terrestrial biodiversity. Moreover, it provides livelihoods for millions of people through many ecosystem services (e.g., supplying clean water, food, fodder, and wood) [52, 59]. In addition, forests are crucial to mitigate the effects of CC, so their sustainable management becomes crucial to improve society's challenges [59].

Reforestation is a crucial NbS adopted to mitigate desertification and contributing to ecosystems restoration. Forest plantation programs with the support of international cooperation were strategies adopted by different Cabo Verdean governments, both from pre-and post-independence of the archipelago [60] and always aimed at protecting the lands from desertification and improving the productive base of the rural sector [58, 61, 62]. The dedication to this program was so great that in 2004 the archipelago had already reached 90,000 ha of reforested area compared to the ca. 3000 ha back in 1975 [60]. In practice, reforestation associated with different soil treatment techniques adopted (e.g., benched terracing, contour terraces, contour ditches, and half-moons) has worked based on Ecosystem restoration approaches (ERA) and Ecosystem-based mitigation (EbM). For example, it helped increase rainwater filtration, increasing soils' water retention capacity on slopes, thereby avoiding floods in the nearby regions [62]. On the other hand, the reforestation in the islands contributed to the development of agro-silvopastoral system production and the satisfaction of forage and energy needs (e.g., coal and firewood fuel) in the rural communities [58, 62].

Forestry actions have contributed to changing the Cabo Verdean landscape, helping to reconstitute vegetation cover and increasing avifauna species, namely *Numida meleagris, Coturnix coturnix, Halcyon leucocephala* [58]. But, in the medium term, some of the species used in the reforestation programs, namely *Prosopis juliflora*, *Leucaena leucocephala,* and *Furcraea foetida* proved to be ineffective since they adapted well to the climatic conditions of the islands and thus establishing intense competition with the native flora [58, 62, 63]. Indeed, due to their invasive nature, exotic species have been classified, according to the IUCN Threats Classification, as the second leading cause of threat to Cabo Verde's endemic flora [63]. More recently, approaches to reintroduce native species, particularly the endemic flora, have been more effective, based on species more resilient and adapted to the country's climatic conditions. On the other hand, it reduces the status risk of species some species [62]. In this regard, the Project Reflor-CV ("Building Adaptative Capacity and Resilience of the Forestry Sector in Cabo Verde") financed by the FAO and the European Union, stands out, intending to increase resilience and adaptative capacity to CC and mitigating the effects of desertification [64, 65]. Furthermore, many of these reforestation programs have been excellent environmental education models since plantings are carried out with local communities and schools, awareness of the importance of preserving the environment and its benefits to address some societal challenges.

As an NbS, Forest Landscape Restoration (FLR) may improve the resilience of degraded ecosystems by restoring them [66], helping assist some trivial societal challenges in CV (e.g. desertification, disaster risk reduction), thus meeting the SDG Goal 15 on protecting life on land [30]. However, a more comprehensive interdisciplinary approach that brings together all policymakers and stakeholders is needed. Moreover, sustainable management of forests is necessary to safeguard that the socio-economic benefit does not threaten the conservation of nature, enhancing an ecologically functional plan [11].

Protected areas (PAs), as Ecosystem protection approaches (EPA), are recognized worldwide as instruments that make a vital contribution to the conservation of the natural and cultural resources of the planet. Its functions range from protecting natural habitats and biological resources to maintaining the ecological balance of the regions where they are located [67]. By valuing and conserving the natural biological diversity within the protected areas, it may be possible to govern nature's use sustainably and reasonably share its benefits. Furthermore, maintaining ecosystem resilience may be critical with NbS to address global societal challenges [68]. And so on, they can offer opportunities for rural development and rational use of land, with the consequent creation of jobs, and for research, promotion of environmental education, recreational activities, and tourism.

Cabo Verde's authorities have shown some interest in conserving and safeguarding the archipelago's natural heritage (e.g., flora, fauna, and their habitats), namely through the network of Protected Areas [53, 58]. In 2003 the legislation for special protection of natural spaces was regulated according to the IUCN guidance [67] with seven categories of protected areas identified [58], namely the Integral Nature Reserves, Special Nature Reserves, National Parks, Natural Parks, Natural Monuments, Protected Landscapes and Sites of Scientific Interest. Back in 2015, the national PAs network encompasses 47 different areas, covering c. 63 067 ha land area of the archipelago [63].

Most terrestrial areas identified for protection have been assigned the status of Natural Park, namely Tope de Coroa in Santo Antão, Monte Verde in São Vicente, Monte Gordo in São Nicolau, Serra da Malagueta in Santiago, and Chã das Caldeiras in Fogo [63]. As Natural Park, it is guaranteed that there is not an intense confrontation with the socio-economic and cultural reality of the country, in which most communities and stakeholders are self-dependent, generally dedicated to agriculture, livestock, and other related activities [69]. However, it implies sustainable management and use of the natural resources that do not threaten biodiversity and ecosystems themselves and simultaneously safeguard the resilience of socio-economic systems. For example, because Chã das Caldeiras is classified as a Natural Park, it allows agriculture, someway sustainably practiced. Thus, a particular product only from this region is produced, namely the "wine of Fogo."

Over the past few years, these various protected areas have functioned based on EPA. Thus, allowing the conservation of several species, namely the endemic ones, preventing their extinction, and guaranteeing a sustainable use of the natural resources used in agriculture and livestock, meeting the SDG Goal 15 [30]. However, it will only continue to be viable if there continues to be a political, social and local effort to ensure its sustainable use. On the other hand, the network of protected areas has become an essential tool for promoting sustainable ecotourism in the archipelago. Additionally, these areas can assist in environmental education with schools and surrounding communities [58].

Overcoming Environmental Degradation and Biodiversity Loss in Coastal and Marine Ecosystems

The coastal regions have essential social, cultural, and economic significance. In CV, the interface or transition area between land and sea, coastal areas, is also home to 85% of the archipelago's population. The economy of CV is heavily dependent on fisheries and tourism, and most of the workforce is employed in these sectors [53]. The importance of marine ecosystems, namely the value of living natural resources for human well-being, is becoming increasingly recognized [70–72]. The marine ecosystem provides nutritional, cultural, coastal protection, and monetary benefits to coastal and inland populations. For example, fishing has an economic value for developing countries of more than the US $ 80 billion in export earnings [70]; also, it is a critical source of lipids and micronutrients [73].

The growth of tourism and economic stability can only have a positive relationship in the competitiveness of tourist destinations if there is evidence of protection of biodiversity, development of natural assets, and sound risk management. In addition, local recreation in coastal areas is also an important economic activity, with an unquestionable contribution to health, social, and cultural value [74].

Cabo Verde is considered a vital diversity hotspot. However, it is in the top 11 most threatened marine biodiversity in the world [2]. The loss of biodiversity and environmental degradation involves several species and ecosystems of high socio-economic value. There is deep-sea fish populations, small pelagics, and crustaceans (coastal lobsters), coral species, and many species of molluscs and gastropods [75]. A paradigmatic example of species conservation in the archipelago, namely marine species has been the example of sea turtles. Sea turtles *Caretta caretta,* which ranks 8th in the world index of the 11 most threatened populations, and the pressure on their habitat due to coastal tourism development continue to be captured for their meat. Cabo Verde archipelago is an important nesting point for marine turtles and important feeding grounds for juveniles' turtles (e.g. *Eretmochelys imbricata* and *Chelonia mydas*) and the third most important worldwide site visited by the *Caretta caretta* species [76, 77]. However, the conservation of sea turtles, particularly the *Caretta caretta* species, has shocked a lot with human consumption. For a long time, several NGOs have committed to conserving the marine turtles (e.g. Natura2000; Projeto Vitó; BiosCV; ABICV) to ensure that the country is a worldwide paradise marine turtle nesting.

More efforts have been made to combat the widespread consumption of marine turtles in CV, namely based on law enforcement and legislation (see: [78]), awareness campaigns, and awakening engagement to turtle-based tourism through a non-consumptive use [77, 78]. As a result, the number of tourists that visit the islands for the observation of turtles increases at the time of nesting. For example, the turtle-watching on Boa Vista Islands, with the most important nesting beaches in the archipelago, has generated up to EUR 100,000 per year [77]. This can be a natural solution offering an indirect source of income and more profitable for the families and communities, focusing on the conservation of biodiversity and nature.

Recently the Government of Cabo Verde (GCV) reinforced in a resolution ("*Resolução No. 172/2020*") and defined as a priority for the Blue Economy, for example, fisheries and aquaculture, marine and coastal environment, and Maritime Spatial Planning and Enhancement of Coastal Areas and Bays [75]. However, all the projects and solutions presented focus more on short-term technical cooperation and emergency assistance. On the other hand, societal needs and the development of the Blue Economy (e.g., fisheries, aquaculture, energy extraction, shipping, among others) have been traditionally in disagreement with the conservation of marine biodiversity.

The foundation of societal needs and the Blue Economy interests are conflicting. To reconcile them, NbS proposes to move conservation practice beyond traditional tools. In particular, focus on providing ecological benefits from single habitats or species to integrated solutions with the fisheries sector [Ecosystem-based Adaptation, Ecosystem-based Fisheries Management, and Marine Protected Areas (MPAs)] and broader sectors in the practical implementation of the Blue Economy. The use of resources (e.g., marine) in environmental management integrated into the SDGs is notably highlighted in recent initiatives [30]. Sustainable management of marine resources is essential for several SDGs, including those related to climate-related disaster risk reduction (goal 13), hunger (goal 2), health (goal 3), economic growth (goal 8), sustainable ocean management (goal 14) and poverty (goal 1) [30].

Most SIDS communities and economies are strongly dependent on healthy coast and ocean resources. Considering the general objectives of NbS, it should be noted that in the context of CV marine and coastal ecosystems, specific NbS to specific societal challenges should be considered. Here we discuss the advantage and why the following two NbS could be applied to CV marine coast, Ecosystem-based Adaptation (EbA) and Marine Protected Areas (MPAs). EbA is especially important for enhancing coastal resilience, mainly in islands where natural resource facilities for industry and agriculture are reduced. On the other hand, nature through coastal ecosystems must be seen as the first line of defense against erosion and rising sea levels. Moreover, the natural system, compared to the heavy infrastructure, provides benefits and livelihood opportunities. For example, removing CO_2 from the atmosphere, capturing and filtering pollutants to keep the water clean, recreational opportunities, improving the quality of tourism, and providing food for fish and other commercially important species. Furthermore, healthy marine and coastal ecosystems provide services and goods to local and national economies and communities such as fisheries, tourism, and recreation, protection from erosion and storms [8, 79].

MPAs in West Africa have an essential role in providing ecosystem services mitigating CC impact and can increase the social-economic and ecological resilience of CV coastal communities [80]. An analysis of 32 marine protected areas in West Africa, including two CV areas (Santa Luzia Island and islets, and the eastern part of Boa Vista Island), focused on threats - coastal erosion, overexploitation of natural resources, unmanaged fishing, and pollution - while management measures are aimed at preventing overfishing and overexploitation of terrestrial natural resources. However, management actions are limited to local entities (monitoring, awareness-raising, and surveillance), where the difficulties of low financial, human, and technical resources are added [81]. There is a perception that critical natural habitats in West Africa are losing surface area, including in CV. The beach areas are the most exposed habitats. However, seagrasses, rocky bottoms, and coral reefs are poorly known and poorly monitored [82]. On the one hand, projects such as ResilientSEA aim to improve knowledge to enhance seagrass management in West Africa; other nature-based measures are urgently needed. For example, dissipating wave energy (e.g., coral reefs) to reduce the potential impacts of sea-level rise, strengthening the physical barrier against storm surges and erosion (e.g., coastal dunes), and attenuating wave energy and sustaining sediment and beach stability (e.g., seagrass).

Nature-Based Solutions for Water Security

Water is a renewable resource, but its management remains a concern, as poor planning, inefficient use, population growth, and increasing demand for water can compromise its availability [83]. Nearly 2.1 billion people globally don't have access to clean and safe drinking water. As a result, around 3.4 million people die each year from scarce and contaminated water sources [84]. Lack of clean water increases water mortality, especially in children, and contributes to the increasing prevalence of waterborne diseases, reducing productivity, burdening health services, and causing millions of deaths annually. Dirty water is therefore considered one of the world's biggest killers, particularly of children [84].

Despite the growing concern of the international community about water in the complex framework of climate change at the beginning of this millennium in some regions of the world, in CV, this is not a recent concern [85]. Over the centuries, lack of water has been the dominant problem for man's survival on these islands [86, 87]. It is paradoxical that since the CV archipelago is in the middle of the ocean, its population suffers from a lack of water [83, 84]. One of the commitments made by CV in the 2030 agenda was to minimize technical and commercial water losses and mobilize water supply using renewable energy to ensure a sustainable water management system. Also, by 2030, it intends to increase storage capacity *per* capita through the construction of dams, with several projects underway on various islands. The country has also invested in the construction of 'terraces, tanks, and reservoirs to retain water and increase groundwater infiltration. During the 2020 global COVID-19 crisis, the importance of energy and water and their strong interdependence became more apparent. Essential services, hygiene and sanitation cannot be provided without access to water and energy. This mainly affects the world's poorest communities, making them vulnerable to COVID-19. The Government of Cabo Verde is implementing its Strategic Plan for Sustainable Development, which sets out 39 ambitious development targets for 2017–2021. CV has significantly advanced on integrated development planning related to energy and water. The country has already made significant progress in supplying its ten islands and its 500,000 inhabitants with sustainable energy from renewable sources, including wind and solar. Independent power producers, local utilities, and public–private partnerships contribute to a balanced power supply and water desalination [88, 89].

New searches for water security solutions are emerging globally, where about 60 percent of the world's population lives in regions with extreme water scarcity. In these regions, the resource has been surface and groundwater that sometimes exceeds the available supply, meaning that there is a risk that no additional water will be available for ecosystem use in the future. Water stress is exacerbated by pollution; some 80–90% of all wastewaters in developing countries are discharged directly into surface water bodies, creating severe risks for human health [84, 90]. Many rainwaters and runoff harvesting systems have been used in CV, mainly on an empirical basis. In general, they have been implemented by the Soil and Water Conservation Services and by farmers and peasants themselves, namely:

1. Water from streams is spread over flat areas, generally called "achadas", for agricultural production;
2. The water is collected in the stream bed during the rainy season by channels and drained to the cultivated areas;
3. The catchment areas are prepared and treated to contribute runoff water to the cultivated areas, adjacent crop areas and stored in reservoirs calculated in advance for later use. Individual terraces are used to produce individual plants, more specifically trees [91].

As nature is both the source of water and the consumer itself, the recommended solutions for water safety must consider "water for nature and nature for water". However, nature alone cannot ensure the safety and access of water for people in all circumstances. Therefore, it should be borne in mind that both built and natural infrastructures are necessary for efficient water resources management [90]. Protecting and maintaining water sources also supports the rich diversity of aquatic species found in rivers, lakes, and wetland ecosystems. Furthermore, functioning natural ecosystems can help maintain water quality and, in some cases, high-quality water is a strong foundation for agricultural and economic development. River basin and water resource management, involving a mix of habitat protection and sustainable use, provides an effective solution to safeguarding water supplies and ensuring ecosystem services.

Open managing water has been a challenge in sustainable development and food security regarding agricultural systems. Rainfed agriculture, an old agricultural practice in CV, depends exclusively on rainfall with the production based on the planting of maize and various types of beans, well adapted to this archipelago's climate and soil condition. In contrast, irrigated agriculture systems consist of irrigating crops during the dry season with stored water. This practice finds major obstacles in production due to the scarcity of water resources. Otherwise, there are several types of irrigation systems, such as flooding and drip irrigation. As an NbS approach, the drip irrigation system consists of placing the water supply pipes at strategic points located close to the plant roots [92]. The amount of water available for irrigation is regulated according to soil and crops depending on weather conditions. It represents the advantage of reducing the amount of water used [92].

Capturing water from fog is an alternative for supplying water and an interesting example of complementary between NbS and technology resources (Ecological Engineering Forest (EE)). When adapting to climate change, which is a global concern, capturing water from fog is an alternative source for supplying water to the most remote communities, or those most plagued by a lack of water, in places with this potential. Fog water abstraction studies carried out in Cabo Verde since the 1960s show that exploiting the fog water harvesting technique in mountainous areas may minimize local water shortages. It is a technique that allows the mobilization of a relevant potential resource, especially in these water-scarce areas. The best conditions for capturing water from fog (in quantities always greater than precipitation) are found on the windward-facing slopes, especially in the Serra da Malagueta [93]. Precise data on the effect of fog on the recharge of Cabo Verde's underground aquifers have not yet been described, but it is likely that the country's largest biological reserves are found in regions with microclimates and fog predominances, such as Serra Malagueta (Santiago), Monte Gordo (São Nicolau) or Monte Verde (São Vicente). The endemic plants of these locations have minor adaptations on their leaves that allow them to collect water from the fog, which can be verified by observing soaked areas on the ground under the canopy of these plants. Thus, even though it cannot be precisely quantified, the importance of this phenomenon for the archipelago's plant and animal biodiversity is undeniable [94].

Conclusion

Cabo Verde, as SIDS, has been struggling to ensure sustainable development. Conditioned by its natural geographic isolation, his climatic conditions, more aggravated by climate change, these islands present sparse natural resources, often undervalued and overexploited. The lack of database, financial funding, and scientific research affects conservation and environmental policy management effectiveness. It ultimately affects the development of major socio-economic activities such as agriculture, fishing, tourism, and the well-being of the population. This research concludes that CV will only successfully face the current problems that persist since at least its independence in 1975, and truly prepare for the imminent challenges that threaten its sustainable development, mainly, but not only, food security, water availability and quality, environmental degradation and biodiversity loss, and in addition climate change, if it applies nature-based solutions. NbS will lead to improvements in (a) the management of agriculture, fisheries, and water; (b) strengthening knowledge of fish resources and ecosystems; (c) knowledge of the value of natural resources, and (d) growth of environmental education at all levels of the national education system, rather than limiting it to awareness, monitoring, and surveillance activities only. Monitoring, surveillance, and awareness activities are simple to implement, especially when management measures neglect erosion, pollution, and climate change. We suggest that actions be adapted to the current situation. It requires a much more sustained and coordinated effort. The basis is founded on NbS as action measures, science-based solutions as decision-making arguments, and education-based from early stages as prevention and future vision.

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Chapter 7
Development of Scientific Literacy and the Impact of Environmental Attitudes of Citizens in a Geological Natural Space

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At the current rate, Earth will be an "island" without forests by the end of the century.
(Jorge Paiva - Público *online*, 2021)

Abstract The present work intends to evaluate the impact of an environmental education action on citizens, as a process to be explored for the development of scientific literacy among the general public. Through the implementation of a pedestrian route in a natural environment (namely, with relevant geological aspects), the acquisition of skills and knowledge, which enhance the development of the scientific culture of the citizens, was promoted. The scientific public awareness project presented here

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was defined as an Interpretative Pedestrian Route in Gerês Mountains (natural protection area of the Peneda-Gerês National Park) in Portugal. The study also intended to verify the citizen's motivation in the search for quality nature tourism and to stimulate reflection on the importance of contact with nature, promoting accountability in the protection of the local natural/historical heritage. The pluri-methodological approach, supported by quantitative and qualitative techniques, allowed us to obtain the data that support the described conclusions. The participant-observation technique was used, and surveys were carried out through questionnaires to the participants ($n = 10$). The results showed that the promoted activity caught the attention of the participants, even those with little knowledge in geology, concluding that it boosted the curiosity and interest of the public in understanding the scientific aspects evidenced in the pedestrian route, contributing to the development of scientific culture of citizens. The study also demonstrated the relevance of pedestrian route, in understanding the interaction of terrestrial subsystems and the holistic approach to the Earth system, as a teaching and also a public awareness activity.

Keywords Environmental education · Non-formal education · Interpretative pedestrian route · Geology · Scientific culture · Sustainability

Introduction

We live in a world completely reconfigured by anthropic activity, in which the human being is such a dominant agent of change that the term Anthropocene is used to describe the current geological epoch of Earth's history [1]. Since the end of the last glaciation, humans have caused a change in the balance of the planet, with clear evidence confirming unprecedented global environmental changes, highlighting some examples such as the destruction of forests and natural habitats, the extinction of species, the alteration of the natural course of rivers, the accumulation of plastics and the spread of different forms of pollution contributing to the acceleration of global climate change [2]. However, the overexploitation of natural resources and ecosystem services can compromise society's ability to meet the essential needs of future populations, and it is undeniable that this impact has grown dramatically in recent centuries, triggering strong negative consequences in the Earth system, such as the emergence from pandemics, ocean contamination, climate change and the growing carbon footprint associated with the burning of fossil fuels [3]. In this regard, refers Lambertini [4], "The *Living Planet Report 2020* clearly outlines humanity's increasing destruction of nature is having catastrophic impacts not only on wildlife populations but also on human health and all aspects of our lives" (p. 4). While it is desirable for all individuals to actively participate in problem solving and collective decision-making, many feel unable to at least understand the magnitude of the issues and their implications in a world definitely immersed in science and technology [5]. The quality of life of society increasingly depends on science, making this part, directly or indirectly, of the daily life of any citizen, so assertive communication and public understanding are increasingly essential [6]. A citizen of the twenty-first century must have a minimum knowledge of the world and have an idea, even if rudimentary, on how to acquire this knowledge [7]. Strengthening scientific culture is a lifelong task, given that, regardless of the degree of scientific culture that each one has, it is always possible to reach higher levels, given that some citizens will develop it more than others, in all domains and dimensions, depending on their motivation, interests and experiences. There is growing evidence that citizens, young and old, value science and need to be informed about the global problems of the Earth system, to get involved and act on their resolution [8], namely, through citizen science. Since 2015, the United Nations with the definition of sustainable development goals, and their adoption in all areas of knowledge, from science to education, the focus on sustainability on Earth has come a long way, teaching, and communicating to all citizens that the Earth is a dynamic system [3]. Thus emerged the development of an ecological awareness at a global level, with the consequent need to reverse the deregulation processes and implement the mitigation of the negative effects of anthropic action in the different terrestrial subsystems, enhancing the continuity and coexistence of human being on the planet. It is urgent to find solutions and answers on a global scale, starting with the local one, involving each and every one of us, in order to ensure a cultural transition to an era of sustainability, in which there is coherence between thinking and acting [9]. The ability to do so implies the development of scientific and environmental literacy and the understanding that we are inevitably participating beings in the planet's subsystems [8]. Despite the immense progress that our species has made in science, medicine, technology and the creation of complex urban societies, according to Howard and Chamberlain [10], nothing is guaranteed about the survival of Homo sapiens, questioning how human beings should face the future of the planet in the face of current climate change, population growth, increasing pressure from the scarcity of natural resources and the relentless growth of new and subtle patterns of disease. All human progress depends on education, especially on science education [11], which justifies the demand of today's society for citizens to have scientific literacy adapted to the new demands of the globalized and technologically advanced world. However, educating in sciences is not about promoting the memorization of scientific terms, but rather, privileging learning situations that enable individuals to develop their scientific culture. Science education must prioritize the formation of scientifically literate citizens who enable them to participate actively and responsibly in an open and democratic society [12, 13]. In addition to helping citizens not only understand the world they live in and which is immersed in science, science education should also help to understand the existence of many non-scientific factors, namely in the context of scientific applications, which contribute for citizens to define positions and make decisions in scientific and technological matters [5]. Only scientifically informed citizens will be able to develop awareness of the impact of their actions on Earth in emerging situations, such as the current climate change, the need to explore new mineral resources, the sustainable use of water resources and the protection of biodiversity and geodiversity [8]. Earth Sciences (or Geosciences), in general, and Geology, in particular, embody precious ways of teaching and learning that stimulate and broaden curiosity about the world, allowing the construction of coherent reasoning about the basic constituents, organization and dynamics of natural systems [14]. The education and teaching of Geology are, therefore, essential to the development of different skills, which compete with an eclectic scientific culture, useful for the performance of enlightened citizenship in current and future society [15]. The importance of geological time for general thinking, according to an adequate reasoning model to face the challenges of the twenty-first century, is mentioned by several authors [16–19], with the understanding of the concept having a significant relevance in scientific literacy. Geological time allows us to understand many of the great changes in Earth History, not only identifying and locating its existence in the past, but also perceiving some cyclical rhythm in these occurrences, sometimes associated with wrong choices made by societies [20, 21]. Knowing the past is essential to understand the present and help prepare for the future, offering Earth Sciences (or Geosciences) an irreplaceable temporal perspective, since rocks keep the memory of the Earth's past, but also of the living beings that populated it, containing important information to understand the origin of life, the evolution of organisms, the causes of great extinctions or the origin of the human species [9]. The promotion of environmental education for sustainable development must be based on a perspective of greater protectionism of the Earth system, implying, for this, a greater critical capacity of the citizen to influence the resolution of environmental problems [22]. The field of study of Earth Systems Science promotes a holistic view of the Earth system, namely, reinforcing the interconnections between its subsystems (biosphere, atmosphere, hydrosphere and geosphere) [23]. And that's why, as we begin to understand, in a deeper way, the Earth as an interactive system, it becomes evident that recent human activities have had a profound impact on the planet, exploring it to the point of a level whose consequences will be unpredictable [24]. As this concern is not new, it is urgent to develop education and public awareness that the Earth behaves as a systemic system, and it is up to humanity to provide for its sustainability, guaranteeing, and only then, the preservation and survival of the human species [25]. It is, therefore, essential to foster environmental literacy and the understanding that we are all beings unavoidably participating in the Earth's subsystems, and that our behaviour is constantly affecting and being affected by everything that is natural and human, in a dynamic relationship [25, 26]. Science cannot ignore its social context, and the concerns and knowledge of those who investigate must be shared with the common citizen, namely, through educational activities developed in non-formal spaces, providing and motivating contextualized learning, when carefully elaborated and outlined for a well-defined goal. The formation of responsible and socially aware citizens is, therefore, one of the aims of education in general, which cannot be confined to laboratory teaching or be confined to the classroom, but extends to the social environment [27, 28]. The "visibility" of non-formal educational processes occurs and asserts itself progressively from the second half of the twentieth century onwards and corresponds to a phenomenon that arises from within an emerging field of educational practices aimed at adult audiences [29]. In non-formal education, educational spaces are located in territories that follow the life trajectories of groups and individuals, outside schools, in informal places, where there are intentional interactive processes [30]. The undeniable advantage of learning in this context is that it is developed according to the will of individuals. Articulated with citizen education (of a participatory nature), non-formal education is aimed at the formation of free, emancipated citizens, holders of a diverse range of rights, but also of duties towards the other(s) [31], being an important tool in the process of formation and construction of people's citizenship, at any social or educational level, highlighting its relevance in the field of youth. The learning generated and shared through non-formal education is not spontaneous, since the processes that lead to it have specific intentions and proposals. Implementing walking routes in an outdoor environment is a promising strategy in the development off attitudes and values of respect for nature and its preservation, as well as for raise awareness of the aesthetic aspects of the environment [32]. Interpretive walking routes, as an outdoor activity integrated in non-formal education [33], should have as its main objective to contribute to the scientific literacy of its participants, also allowing the development of scientific, technological, social and affective objectives, intending to be, therefore, holistic activities [34], while giving a preponderant emphasis, to scientific public awareness, if possible, to environmental problems [35]. When the activity is carried out in a natural environment, such as in a protected natural area, it is a valuable tool in the promotion of scientific culture, using actions related to the investigation of environmental problems, namely, pollution, deforestation, or fire. Pedestrian routes in a natural environment often follow the orientation of the organizational model of Nir Orion's fieldwork [36], with a structuring and implementation of a trip according to a three-dimensional development of the learning cycle (Fig. 7.1), in which the hierarchy of concepts takes place in a spiral movement, from the concrete to the abstract and where the activities developed are interconnected.

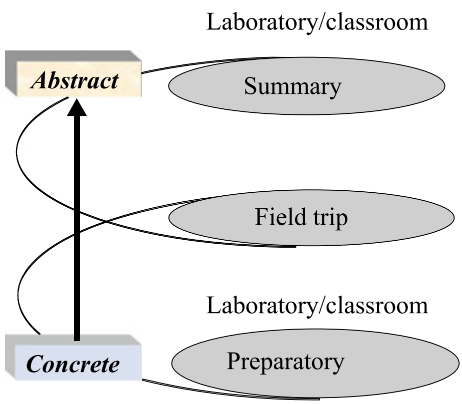

Fig. 7.1 Model of the structure of the Field Trip Unit, according to the spiral model of integrating an outdoor learning activity within the indoors-learning process (adapted) [36]

Research Problem

The problem of the investigation was to verify if a pedestrian route carried out in a natural environment could promote the scientific culture of the visitors and enhance the place as a tourist attraction. The purpose of the investigation was to promote a place connected with nature, as an excellent resource for environmental education, both in the context of non-formal education and as a space for scientific public awareness.

Pedestrian Route

The Gerês mountain, located within the boundaries of the Peneda-Gerês National Park, was the chosen area for the development of an interpretive route of didactic interest, due to the enormous potential of multidisciplinary aspects, namely, geological, zoological, botanical, and historical, among others, and also, for the great tourist attraction associated with it, with a diverse public, in age, gender and cultural interests. On the other hand, the area makes it possible the realization of interpretive walking routes that allow the development of a scientific and induce a reflection on the importance of contact with nature and its protection, thus constituting a didactic resource to be exploited, being potentially a non-formal learning.

The Interpretive Pedestrian Route "Minas do Borrageiro—Lagoa do Marinho" (Fig. 7.2), was intended to provide the public with a minimum of restlessness and curiosity, and the possibility of getting to know the place through questions that arose during a detailed observation of it, in particular, at some of the planned stops. This non-formal teaching space allows for a learning with specific characteristics, as it is spontaneous and individual, without any imposition on the visitor, being also playful, appealing and enhancing civic attitudes and immediate confrontation with reality. It also highlight two main ideas that led to the research work: (i) the individuals were receptive to learning, when in a leisure environment, related to knowledge of the area in which they were located; (ii) the strategies to develop contributed to

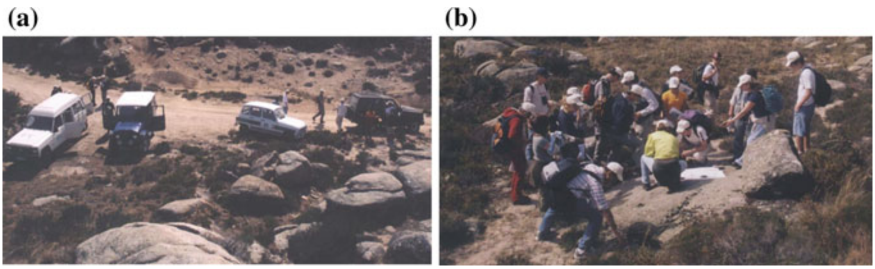

Fig. 7.2 **a** Parking place for the vehicles used to transport the participants; **b** concentration of the working group at the first stop of the walking trail [37]

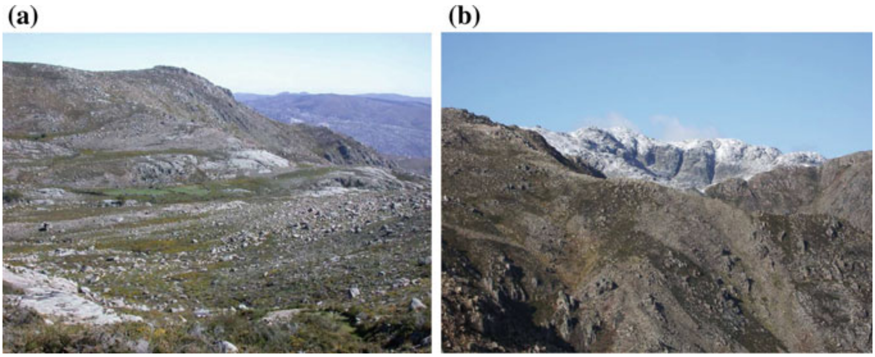

Fig. 7.3 **a** Glacial moraines in the headwaters of Couce river at Gerês mountains; **b** View of the Concelinho Glacier Circus with 1000 m altitude (with snow) [34]

awaken/strengthen innovative activities in the scientific public awareness and in a non-formal/informal teaching framework.

The places where the route and the surrounding extended area, are integrated in a geological environment of magmatic rocks, dominated by two types of granitic rocks: the Gerês and the Borrageiro granite, each with distinct macroscopic characteristics and therefore, liable to be differentiated on site. It is noteworthy the particularity of association with the Borrageiro granite were found traces of ancient mining works for the exploitation of tungsten, contained in quartz veins that cut through this granite. The Gerês and Peneda mountains constitute a relief with high altitudes (around 1500 m) in Northern Portugal. According to Vidal Romani et al. [38], the granitic mountain range of Gerês was subjected to an intensive denudation activity, mainly motivated by glacial and periglacial processes during the last phase of the Pleistocene. Although there are few clearly glacial forms, some traces of glaciations have been identified [37] (Fig. 7.3), in the Alto Vale do Vez and the Cocões de Concelinho—Lagoa do Marinho area (valleys with a U-shape profile; glacial moraines; glacial circus; polished, striated and grooved granite surfaces; etc.). Fluvial, torrential and glacial deposits constitute the most recent geological formations in the National Park area and are present in several spots, with glacial origins being highlighted in Ribeira do Couce, Lagoa do Marinho and in Alto Vale do Rio Vez [39].

In this pedestrian route, the geological characteristics of the natural environment located in this preserved area were highlighted in the hope of the promotion of the scientific public awareness of the visitor and turn it as a tourist attraction.

Methodology

Method and Techniques

The evaluation study carried out did not intend to make generalizations, but rather to allow the reader to reach their own conclusions, emphasizing the context in which the investigation took place in order to assess the transferability of the study results to other situations. A descriptive case study was developed, supported by the qualitative and quantitative method, using the technique of participant observation, with the researcher (first author of the work) assuming an active role throughout the intervention. A descriptive case study was developed, supported by the qualitative and quantitative method, using the technique of participant observation, with the researcher (first author of the work) assuming an active role throughout the intervention. The investigation used two data collection techniques: observation (direct method) and questionnaire survey (indirect method). The observation technique directly appeals to the researcher's sense of analysis, who follows the experiences lived in loco, without, however, addressing the interested subjects. Specifically, naturalistic observation was used, a qualitative investigation technique, which allows the use of recording instruments, without influencing the target group, which allows controlling the variables to be observed, in which the researcher has as a direct source of collection situations considered "natural", interacting with the subjects to be evaluated in a natural and, above all, discreet way. An expert participant in the area, external to the group that constituted the target population of the study, was invited, who used the observation technique to collect data in a neutral way that could be interpreted and evaluated in the two sessions that made up the work—the lecture (1st session) and the pedestrian route (2nd session). The questionnaires, presented in writing to the participants, contained several questions (Questionnaire A—31 questions; Questionnaire B—18 questions), of the open type, multiple choice and ordering, in order to know aspects such as opinions, beliefs, feelings, interests, expectations, situations experienced, skills and knowledge of respondents in the areas of Geology, Biology and Environment, among other convenient points for research. The data measured from questionnaire A served as the basis for the construction of some of the materials used, namely, the activities book and the mini-posters presented.

Sample

The selection of the sample was intended, in the sense of being potentially representative individuals of the population, potential visitors to the PNPG, knowing a priori that they had characteristics that made them important indicators for the study in question. Safeguarding the availability of interested parties, the route took place at the weekend, on two consecutive Saturdays (on the 1st Saturday, the clarification session/lecture took place; on the 2nd Saturday, the pedestrian route corresponding to the second study session), implying the mandatory presence of all participants in the two sessions held. Due to the characteristics of the study area (located in an unpopulated region that is part of the Partial Protection Natural Environment Area defined in the 1991 Land Use Plan) and the number of vehicles needed to transport participants to the location of the pedestrian path, it is conditioned to circulation, the number of participants was subject to a limited number of entries (minimum 10 elements and maximum 15). The public awareness of the activity was done by invitation sent via e-mail to some people who were known to have a taste for hiking and contact with nature and who, through these, transmitted the invitation to other people equally interested in participating, resulted in 12 individuals enrolled, all of whom attended the first debriefing session. Later, in the second session, only 10 people appeared at the meeting place for the pedestrian route. The study sample was considered to consist only of the subjects participating in both sessions (n = 10). This one consisted of five men and five women, aged mostly between 40 and 64 years old, with three elements outside this age group (with 14, 21 and 33 years old). Regarding education and educational qualifications, 3 individuals had attended the elementary school up to the 9^{th} grade of elementary school, 4 up to the 12th grade of high school, 1 had a bachelor's degree in Economics and 2 had a degree in Sociology and Economics. Participants had different professions, such as Insurance Technician, Banking, Senior Administrative Technician, Computer Technician, Navigation Operational, Secretary, Insurance Mediator, Student and 2 elements of the sample were retired.

Procedure

Two written questionnaires were prepared, Questionnaire A and Questionnaire B, both of which must be completed, with the respondents being guaranteed the anonymous and confidential nature of the results expressed. Questionnaire A was distributed to participants in the activity preparation session and at the beginning of the activity (pre-activity phase), with the aim of characterizing the selected individuals, assessing the motivation and interest of those involved in participating in outdoor activities, diagnose skills and knowledge in the areas of Geology, Biology and Environment, as well as collect aspects about the values and attitudes of respondents towards environmental education. Questionnaire B was applied at the end of the pedestrian route (post-activity phase), to verify the impact of all the action implemented on the participants. The outdoor environment activity developed was planned in accordance with Nir Orion's organizational model, adapted for this purpose, taking into account the target audience it was aimed at. In the preparation phase of the activity, data regarding the development of the research were communicated to the participants, namely, scope, objectives, work team/researchers, moments of mandatory physical participation of the participants, and also a lecture was held for the identification and scientific context of the area of study, essential for prior recognition of the pedestrian route to be undertaken. For this purpose, digital means were developed and used, namely, a video about the Gerês mountain and digital animations explaining the glaciation episodes that occurred during the Pleistocene, in the study area.

Results and Discussion

The data obtained from the information provided in the questionnaires completed by the participants (A and B) were analyzed, not intending to generalize the results, but rather to induce a reflection on the importance of natural spaces in the acquisition of a scientific culture for citizens. In addition to the quantitative technique, the naturalistic observation carried out was also analyzed, to reduce the subjectivity inherent in the interpretations, and legitimize the conclusions reached by the data triangulation. As this was a small sample ($n = 10$), descriptive statistics were presented, using some tables to facilitate the reading and interpretation of the results. Considering the limitation in the size of the work, the results of the questions considered relevant for the conclusion are presented.

Questionnaire A

Most participants ($n = 8$) revealed not only knowledge about the concept of Natural Protection Area, but also the notion of the negative impact of human being on these natural spaces (fires, hunting), referring to the importance of non-human intervention, essential for the preservation of habitats and protection of species of local fauna and flora. Eight participants responded that they had read information on the PNPG (in books, newspapers or magazines, scientific articles, leaflets, Internet), with sports activities, tourism (accommodation) and environmental issues being the most cited areas. Only one respondent did not know the PNPG, and the remaining nine stated that they used to visit it once or twice a year, on weekends or holidays. The reasons given for visiting this place were the contact with nature, the pleasure of walking and leisure, although rest, camping, picnics, and health issues were mentioned in a less relevant way. All participants reported having knowledge ($n = 6$) and a lot of knowledge ($n = 4$) about the environment and the aggressions it is subject to, with seven respondents claiming to know the concepts of pollution and urban pressure and three confirming that they know it very well. Regarding specific terms (inorganic waste, organic waste, noise pollution, air pollution and urban pressure), four individuals do not know the meaning of waste, with organic waste being unknown to only one. Most participants separate household garbage on a day-to-day basis ($n = 9$) and temporarily store garbage in the absence of containers ($n = 8$). Six individuals claim to consume refillable products and four assume that they use disposable products whenever.

A minority of the respondents ($n = 3$) identified “I rarely use public transport” and, similarly, “when I drive a car, I usually do it alone”. None of the subjects reported having participated in actions for the defense of the Environment and Natural Heritage developed by Associations or Government Entities, pointing out the lack of time/availability and opportunity as the main reasons. Of the total number of participants, 8 considered environmental education as an important and priority solution to the environmental crisis, in relation to technological solutions. Some answers are cited "…technological solutions are not always functional", "The need for greater awareness on the part of citizens in environmental decision-making, on which our future and future generations depend, thus making technological solutions profitable", "…the lack of information often justifies the absence of this environmental awareness in some of the people, and it is important that it starts at home and goes through school". The youngest element did not issue an opinion (n = 1). When several options were presented to justify the participation in the Interpretative Pedestrial Route activity, stands out the contact with nature (n = 9) and the type of planned activity were signed by most individuals (n = 8), followed by others such as being an activity inserted in a protected area (n = 7), addressing issues related to environmental education activities (n = 6) and by socializing with other people (n = 6). There is a preference for contact with nature (n = 9), followed by issues related to environmental education (n = 8) and a taste for activities developed in protected areas (n = 7). Most respondents (n = 8) stated that they do not usually participate in similar activities around Geology and/or environment, and only two persons do, considering the most important and motivating factor in these activities to be the pleasure of contact with the nature, the discovery of new species that it does not know, as well as the enrichment of its general culture.

Table 7.1 presents the answers obtained in relation to the list of concepts of Geology and Biology presented to the respondents, regarding the degree of knowledge of each one.

The areas of geology that arouse the greatest interest and curiosity are, cumulatively, fossils (n = 6), followed by soils (n = 4) and plate tectonics (n = 4), and geomorphology (n = 2) and minerals and ornamental rocks (n = 1) along with minerals and precious stones (n = 1).

The open question about the role of the citizen in solving the problems that society is currently facing, namely, environmental ones, some of the answers: "It is up to everyone, as long as they are educated, to contribute so that it is not necessary to solve, but prevent"; "The awareness for the preservation of the environment, taking into account aspects such as pollution…"; "Raising awareness among government officials, in addition to the individual attitude of each one!"; "Being intervening and not adopting a passive posture"; "Garbage separation, saving resources…"; "Small daily individual actions can contribute to solving the great problems of society in terms of major environmental issues" and "Changing people's mindsets". It should be noted that, of the 10 participants, only one did not issue an opinion.

Table 7.1 Distribution of answers given by individuals (n = 10), regarding the degree of knowledge of each of the concepts related to Geology and Biology [37]

Geology concepts	I don't know	I know	I know well
Granite	0	7	3
Megacrystal	8	2	0
Minerals	1	9	0
Vein	3	7	0
Inselberg	10	0	0
Diaclase	8	2	0
Ore	1	9	0
Fault	3	7	0
Polishing surface	3	7	0
Moraine	7	3	0
Giant's kettle	5	4	1
Granite tower (*tor*)	6	4	0
Granitic block	2	8	0
Block Chaos	7	2	1
Differential erosion	8	2	0
Quartz, feldspar and micas	2	6	2
Pegmatite	10	0	0
Plutonic rock	7	3	0
Outcrop	6	3	0
Glacier circus	3	7	0
Biology concepts			
Lichen	4	5	1
Autochthonous flora	2	8	0
Endemic vegetation	7	3	0
Fauna	2	8	0
Environment concepts			
Environmental aggression	0	6	4
Organic residues	4	6	0
Inorganic residues	5	5	0
Atmospheric pollution	0	7	3
Noise pollution	0	7	3
Urban pressure	0	7	3

Questionnaire B

Table 7.2 describes the participants' assessment of the quality of the materials used in the two sessions held, revealing an even distribution between the "good" and "very good" responses.

All respondents (n = 10) considered the number of materials used to have been "sufficient", to have been "clarifying" (n = 6) and "very enlightening" (n = 4). Regarding the clarification session, they report that it was "indispensable" (n = 6) for the development and understanding of the walking route, and only "Necessary and adequate" for 4 participants. Some of the answers are transcribed: "…very easily explained the fundamental basics of Geology. I was impressed!", "…rich in content

Table 7.2 Distribution of responses given by individuals regarding the usefulness of each of the materials used during the activity, in the two sessions (n = 10) [37]

	Quality			
Materials	Good	Very good	Reasonable	Bad
Invitation	5	5	0	0
Multimedia presentation (3D digital animation models)	4	6	0	0
Movie "A look at the Gerês mountains…"	7	3	0	0
Information leaflet	6	4	0	0
Notebook activity	5	5	0	0
Mini-posters	6	4	0	0

and very well presented", "All clarifications were provided in a clear and well-connected way", "They demonstrated that they mastered the material presented", "I was elucidated", "I learned some new things". As materials considered most useful and providing more information, all highlighted the activities notebook (n = 10), the film "A look at Gerês mountain …" (n = 7) and the multimedia presentation and the information leaflet (n = 10) = 6). Only 1 individual considered the mini-posters useful, in the set of three materials.

In this context, it can be read: "Having knowledge of the route", "…organization and transparency of the subject in a clear and objective way", "…they informed everything very well in a very simple way", "Unknown information has become very familiar after the information given", "We had a better explanation of each thing we observed", "Successive demonstrations spaced in time and space". Given the activities developed and the characteristics of the walking route, the 10 participants considered the number of participants "adequate". The results of the assessment of the activities developed were distributed as shown in Table 7.3.

In general, the participants liked the proposals that were addressed to them, highlighting eight of the participants who reported having liked a lot the pedestrian route. Some answers given about the activity: "It made me more interested in science and in particular in Geology" (n = 5), "It increased my respect for the natural heritage" (n = 4), "I developed the spirit of observation about Nature (n = 4), "I learned new concepts, with a consequent increase in my "general culture" (n = 6), "I understood some phenomena that occur in the landscape of Gerês" (n = 5), "It called my attention to participation in future activities of the kind" (n = 3), "It made me aware of reflection on environmental issues" (n = 1), "I think I am able to mobilize the scientific and technological knowledge I acquired by applying it to other landscapes" (n = 2). All participants (n = 10) considered it important to carry out this type of activity, in the area of Geology and/or Environment, presenting the following justifications: "They raise awareness for the preservation of nature and respect for the environment", "They are important and should continue to develop to get to know our world better, how to explore and preserve the various natural resources", "They contribute to good environmental education", "Only on the ground can we understand all the concepts…and understand some landscapes", "They allow to increase

Table 7.3 Results of the appraisal of the proposed work activities (n = 10) [37]

Works and proposed activities	Liked a lot	Liked	Liked a little	Didn‘t like
Lecture	4	6	0	0
Movie “A look at the Gerês mountains…”	6	4	0	0
Interpretative pedestrian route	8	2	0	0
Observation of aspects related to the Gerês and Borrageiro granite	5	4	1	0
Observation and understanding of aspects related to geomorphology	7	3	0	0
Mineral identification and/or ores from Mina do Borrageiro	6	4	0	0
Compass use for determination of direction of observed structures	4	4	2	0
Observation and understanding of aspects related to environment	6	3	1	0
Reflection and discussion on the aspects observed	4	6	0	0
Interpretation of the problem situations	2	5	3	0
Resolution of activity notebook proposals	6	3	1	0

personal knowledge” and, further, “They increase the value that people place on natural heritage, when they learn to interpret it”. And still, they left suggestions for future work: “Do more actions to observe the environment and, mainly, to raise awareness of the impact we have on nature”, “Development of other walking routes for fauna observation”, “Repeat these actions frequently, the same in terms of lectures and interpretive routes”, “Visits to other areas of the country with specific geology”, “More walks”, “I loved having participated in the tour to Gerês. It was very instructive, and the scenery is fantastic. There’s nothing like being in the middle of nature.”, “Thank you for the great cultural tour you gave us. It was really nice to revisit an area that I already knew, but with different eyes and at a slow pace…sometimes it’s good to walk slowly!

Naturalist Observation

The collected data that constitute the observed: (i) the lecture – session clarifying the conceptual framework of the area under analysis; and (ii) the pedestrian route - as a practical activity that consolidates the knowledge built and the skills to be promoted. The duration of the lecture, although time consuming (30 min to complete the questionnaire and 1 h and 30 min for the session), was not considered excessive or tiring, with the participants being motivated, hence their presence and concentration. In addition to the specialist in the subject under study, invited to address the geological setting of the area, the promoter of the session relied on various teaching resources to streamline the action, including the modelling strategy, whose innovative character favoured motivation and participants' understanding of geological processes. From the above, a very positive characterization of the session stands out, although it is worth mentioning: (i) lack of explicit references to the promotion of skills development; and (ii) in terms of practical application in a real situation, the duration of the lecture will inevitably have to be shortened. The visualization and interpretation of the area in geological terms stand out, as the most relevant objectives and the development of competences, especially in terms of mobilizing attitudes towards environmental protection. Various resources were made available and handled, such as a compass, GPS, magnet, topographical map and geologist's hammer (characteristics of any field trip). Mini-posters were presented that helped in the explanation and understanding of some observations/interpretations in the field, and a field guide was provided to the participants with carefully selected stops, and with guidelines for carrying out tasks and problem-questions that could arise during the route. In addition to the description of geological phenomena, the monitor tried to enhance their interpretation, appealing to the participants' reflection and careful and careful observation. Participants worked in groups and individually and performed/discussed field guide activities with peers. The language used by the monitor and the degree of complexity of the approach in geological terms was extremely adequate to the type of participants and the purposes of the action. The data point towards an interpretive walking path that fulfilled its main objective—public awareness of the geology of the area to a group of citizens with rudimentary knowledge in geological terms and, although more enlightened, strengthening skills in the environmental protection knowledge.

The participants had some knowledge of Geology, however, despite having claimed to know the concepts described, their conceptualization was not clear, since, during the walking route, some of these concepts seemed to them new. The association with misconceptions can justify the significant increase in knowledge about the terms that was found at the end of the activity, with reconceptualization. On the other hand, some terms might be familiar to them without really knowing their meaning. In relation to questions about the environment, there was a greater knowledge of this area, probably since there are awareness campaigns, being a matter of greater public awareness of information, making these concepts part of the general knowledge of the population. Participants were sensitized to issues related to environmental problems and the role that each one of us should have in preventing and/or solving these problems. About the concepts of Biology, although not so evident, there was also a higher percentage of knowledge when compared to those of Geology. Because they involve concepts that are more accessible to capture and understand, this may underlie the difference in the results obtained between these two areas, with Geology being of greater complexity and need for abstraction to understand phenomena and associated processes, as a hermeneutic (interpretative) science and historical [18]. The digital means used in the planning and implementation of the activity with the participants stand out, as an innovative factor facilitating the understanding of the geological processes and phenomena discussed along the way, in particular, the realization and projection of the film about the Gerês mountain, the multimedia presentation and the implementation of the digital animation models (3D) used to explain the glaciation phenomena that occurred at the location of the pedestrian route. This type of multimedia production tool is [40] particularly useful in Geology, as it allows recreating, in a very short time, geological processes that normally take place over thousands or millions of years. Some dispersion of the group when traveling between some stops is justified by the interest shown by the participants in specific aspects of the route, staying longer than expected in the place or going further along the route attracted by something that caught their attention. The general comments obtained at the end of the activity demonstrate that all individuals enjoyed participating in it and learned something new about Gerês mountain, mentioning the possible participation in future actions of the kind. Participants also regretted that there were no more actions of this kind and requested that they be extended to other parts of the country, with the public awareness of geological aspects in other places. The data obtained by the naturalist observation pointed towards an interpretive walking route that fulfilled its main objective, the public awareness of the geology of the area to a group of citizens with rudimentary knowledge in geological terms and, although more enlightened, the reinforcement of skills in environmental protection.

Conclusion

The data point towards an Interpretive Pedestrian Route that fulfilled its main objective—public awareness of the geology of the area to a group of citizens with rudimentary knowledge in geological terms and, although more enlightened, strengthening skills in environmental protection. On the other hand, the organizational model adopted is close to that of Nir Orion [36], either by reducing the “novelty space” in the lecture, or by the care inherent in carrying out the route. Despite the small sample, the pluri-methodological approach allowed us to verify that the activity carried out had a positive impact on the participants, reinforcing the importance of pedestrian routes in the integration of geology and environmental education. The study also demonstrated the relevance of activities in an outdoor environment, namely, the pedestrian routes, in understanding the interaction of terrestrial subsystems and the holistic approach to the Earth system, as a teaching and a public awareness activity. The promotion of pedestrian routes in natural environmental spaces is, therefore, a practice to be fostered in the promotion of scientific literacy of citizens in an atmosphere involving scientific culture and, therefore, in the teaching and public awareness of Geosciences. Only in this way will it be possible to increase the scientific culture of citizens, making scientific knowledge part of their general culture, so that conscious and active intervention in public debates and participation in the prevention and/or resolution of emerging environmental problems can be verified. Pedestrian routes in a natural environment are also a valuable tool for promoting environmental education. It should be noted, even so, that the citizen’s motivation in seeking information and interest in participating in these activities are essential aspects to be considered in the development and success of any action.

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Chapter 8
A Problem-Based Learning Approach to Environmental Education Through a Field Trip and a Science Centre Visit

Manuella Villar Amado

Abstract The development of science and technology currently experienced by society has brought a degree of quality of life that humanity has never experienced before, but it has also created environmental problems that represent real challenges for today and the future. In this period known as the Anthropocene, teachers of basic education face the challenging task of preparing individuals for a world that is in constant transformation. In this context, it is necessary to establish teaching and learning strategies that will enable individuals to effectively solve existing problems, to make rational decisions, and to fully participate in a democratic society. Accordingly, this study presents an Intervention Program (IP) for scientific literacy, based upon and validated as a teaching strategy, centred on the Problem-Based Learning methodology (PBL), and applied to two different contexts of non-formal education, a field trip and a Science Centre visit. The research aims to directly contribute to teacher training, which in turn will produce long term effects on elementary school students, thereby contributing to sustainability. It is a qualitative study with 15 students in non-formal education, as part of a curricular unit from a professional master's degree in Science and Mathematics Teaching, which is taught in a federal institution in south-east Brazil. A methodological triangulation was applied with different instruments and data collection techniques, namely: logbook, questionnaires, focus groups, monitoring reports, PBL record, and student production (Teacher Guide and Sustainability Game). The development of the IP involved two scenarios of the PBL methodology and the construction and validation of scenarios with peers. The results led to the conclusion that, when applied to non-formal education spaces, PBL enhances distinctive features of teacher training (such as a privileged space for reflecting on education, its complexity, and the possibilities of transdisciplinary teaching practices), in addition to favouring the acquisition of knowledge that will promote attitudes concerned with sustainable development.

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Keywords Environmental education · Anthropocene · Sustainability · Problem-based learning methodology

> Humanity needs more open minds, more sensitive listening, people who are responsible and committed to transforming themselves and the world!
>
> (Edgar Morin)

Introduction

Today we are living in the midst of an advancing socio-environmental crisis on a planetary scale, with serious ecological and socio-economic implications, migration and poverty, social inequalities, unemployment, environmental exploitation, and degradation and resource extraction. The term "Anthropocene" has been used to better describe the present epoch, in which the human species (Homo sapiens) has generated impacts on nature equivalent to a geological force capable of modifying the planet's biophysical parameters [1].

In the Anthropocene, the exploitation of environmental resources has caused worldwide degradation of forests, especially in tropical countries [2]. Brazil contains 22% of the planet's and 58% of South America's humid tropical forests [3]. However, deforestation rates here are also among the highest in the world [4]. This a period of endless crises due to globalization, westernization, and unsustainable development.

Edgar Morin [5] is emphatic when he says, there are only two paths, the abyss or metamorphosis. The direction of this second path needs to be carefully planned out. Some researchers [6, 7] believe that educational institutions have great potential for generating multipliers for socio-environmental sustainability.

In this context, it is necessary to establish teaching and learning strategies that will enable individuals to effectively solve existing socio-environmental problems, to make rational decisions, and to fully participate in a democratic society. Accordingly, this research presents an Intervention Program (IP) for environmental education, based upon and validated as a teaching strategy, centred on the Problem-Based Learning methodology (PBL), and applied to two different contexts of non-formal education, a field trip and a Science Centre visit.

Field trips may stimulate the participants' curiosity, their sense of empathy for creatures, and responsibility and unity with nature, maximizing the acquisition of information about nature and, ultimately, changing their conceptions about the importance of environmental conservation [8–10].

Science Centres are a type of museum, which, in the twenty-first century, are coming to be understood as 'polyphonic spaces' concerned with 'planetary well-being' [11]. Therefore, in addition to focussing on traditional concerns, museology needs to keep abreast of debates in global challenges and sustainable development. The ICOM recently adopted sustainability as one of its priority areas.

Problem-based learning (PBL) is a collaborative and participatory student-centred approach to teaching and learning, based on group work and problem exploration

[12]. The main aim of using PBL for sustainability education is for students to investigate real life sustainability problems—which are inherently socio-environmental, open ended, and without a simple solution [12]. Through this process, students develop a greater understanding of the multifaceted nature of sustainability issues and develop interdisciplinary skills in sustainability, as well as a range of professional competencies [12]. This range of skills includes, but is not limited to, effective communication; ethical awareness; global citizenship; discussion and negotiation; listening and respecting others; team work; self- and group-reflection; inter-cultural understanding; systems thinking; creative thinking; and stakeholder engagement [12]. PBL originates from medical education, specifically from McMaster University in Ontario, Canada, where it was pioneered in the 1960s [12]. The application of PBL in elementary schools will not be successful without the seriousness of the teacher, as classes require careful planning [13].

The objective of this study was to contribute to the training of elementary school teachers in Brazil, promoting knowledge acquisition in attitudes towards environmental education, using PBL applied to a field trip and a Science Centre visit.

Methodology

Sample

This is a qualitative study with 15 students in non-formal education, as part of a 30-h curricular unit from a professional master's degree in Science and Mathematics Teaching, which is taught in a federal institution in south-east Brazil. The research subjects were teachers with the following higher-level education: Biology (6), Chemistry (2), Physics (1), Geography (1), Mathematics (1), Social Sciences (1), Pedagogy (1), Civil Engineering (1), and Library Science (1). Most (10) graduated from a public higher education institution. They had an average of 13 years' experience as teachers. The gender distribution was as follows: 10 female students with an average age of 40 years old and 5 male students with an average age of 38.

PBL Process

As a teaching and learning strategy, PBL integrates a set of steps that allow the teacher to mediate the process. There are some proposals for the operationalization of PBL in the scientific literature, although the structuring and terminology used in describing such proposals are not consensual. The proposals presented by three authors for planning the PBL strategy are outlined below.

Almeida [14] mentions five stages of PBL: (i) identification of the problem (reading a statement, presenting a case or exposing a situation); (ii) problem analysis; (iii) synthesis of explanations, setting of objectives, decision making; (iv) systematization of the solutions found and application to real contexts; and (v) continuous assessment by students and teachers.

Trindade [15] suggests three steps for planning the teaching and learning strategy: (i) selection of the core notion to be addressed; (ii) formalization of the problem situation; and (iii) elaboration of a framework of activities to be carried out and resources to be used.

Delisle [16] presents the following PBL plan: (i) select content and competences; (ii) inventory available resources; (iii) write the problem statement; (iv) choose a motivating activity; (v) develop a focused question (end product); and (vi) define an evaluative strategy.

In this study we opted to use a plan based on the PBL stages presented by Vasconcelos and Almeida [17]. The choice of the Cycle Process is justified, essentially, for two reasons. Firstly, among the proposals found in the literature, the work of Vasconcelos and Almeida [17] is configured as one of the most exhaustive in strategy presentation. Secondly, the work of these authors includes several practical examples of strategic planning in the classroom at different levels of basic education, an aspect that appeared to facilitate its development. These authors adapted the structure into mandatory phases initially created by Lambros [18], which involves the heuristic steps shown in Fig. 8.1.

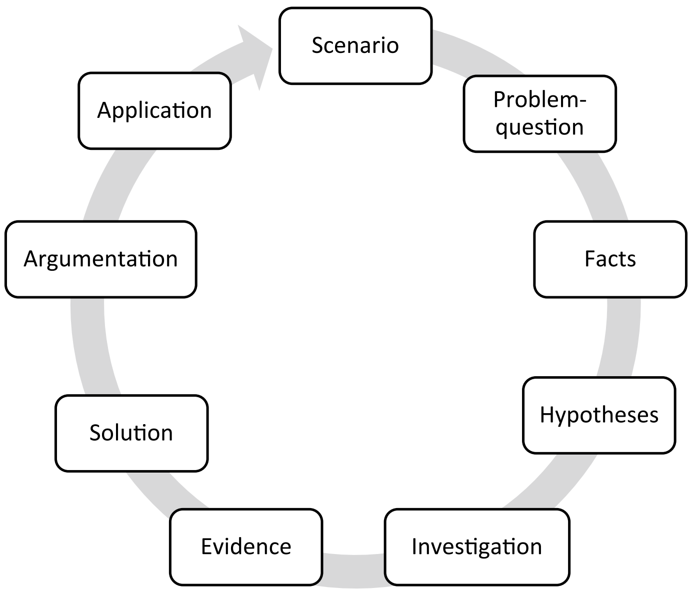

Fig. 8.1 PBL cycle process (adapted from Vasconcelos and Almeida (2012) (p.2))

Thus, the two scenarios (Scenario 1 and Scenario 2) built in this work followed the PBL plan of Vasconcelos and Almeida [17] and were based on the following structure:

(1) Title—name given to the problematic scenario.
(2) Curricular contextualization—indication of the level of education.
(3) Estimated time—time needed to carry out the proposed work.
(4) Prerequisites—correspond to the knowledge learned in previous years and that will help in the questioning and planning of the research activity to be developed.
(5) Objectives—related to knowledge and ability that students are expected to achieve with the development of research.
(6) Concepts – they are disseminated in school manuals or subject menus. They must be implicit to the selected theme and to the objectives to be achieved.
(7) Scenario—refers to problematic contextualization and can be presented in several ways: texts, news, photographs, or dialogues.
(8) Problem-questions—the planning of this item involves questions raised by the teacher, who tries to foresee the possible questions that will be raised by the students. During the intervention, it is at this stage that the students receive the PBL monitoring form to highlight the facts and raise their questions.
(9) Final product—is the expected product as a result of the research work.
(10) Data Sources—are consultation elements for students to find evidence to answer the problem-questions and have more information to contribute when communicating the proposed solutions to the class.
(11) Disciplinary articulation—indicate the connections of concepts between units of the same discipline or between different disciplinary areas.
(12) Presentation cycle—presents the sequence of activities that will be developed
(13) Application—allows you to assess the knowledge learned for applications involving critical thinking, scientific reasoning, and argumentation skills.

The Intervention Program (IP) consisted of classes and activities developed in two scenarios, Scenario 1 with a Science Centre visit and Scenario 2 with a field trip. After participating in the two scenarios, the students gathered into groups and planned a PBL scenario to be applied to a field trip or a visit to a Science Centre with elementary school students. On the last day of class, the groups presented the scenario and validated it through a questionnaire on the PBL plan of the other group (Fig. 8.2).

PBL Scenario 1—Science Centre Visit

Scenario 1 aimed to work on the definitions of non-formal, formal, and informal education; explore the concepts of museums and Science Centres, knowing the environments of museums and Science Centres; know the history of museums in Brazil; and create a work proposal for a Science Centre visit with the socio-environmental

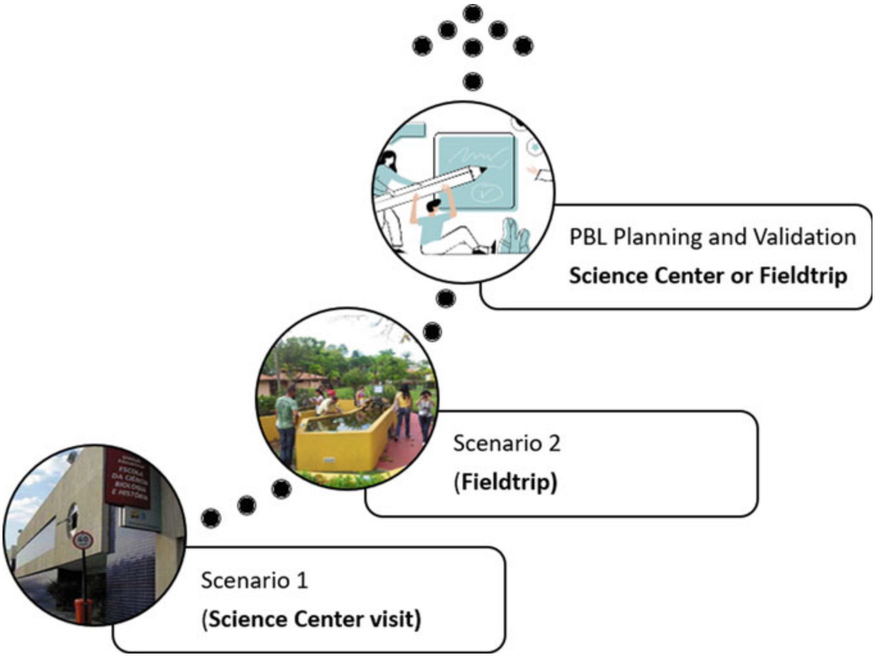

Fig. 8.2 Intervention Program (IP)

perspective of environmental education. Scenario 1 was structured in the sequence presented in Table 8.1.

The activities began with the presentation of the discipline's program and the research objectives. The first activity was a dialogic expository class where formal, non-formal, and informal education concepts were discussed. In the second activity,

Table 8.1 Scenario 1 presentation cycle

Class number (h)	Activity
2	– IP presentation – Research objectives presentation
2	– Concepts of formal, informal, and non-formal education presentations
4	– Science Centre visit: Escola de Ciências, Biologia, e História
2	– Reading a scenario – Online Museums visit in the computer lab – Formation of groups and filling out the PBL monitoring form
2	– Group dynamics: The web of life versus the web of knowledge – Reading and discussion of questions and answers – Concept reinforcement – Product presentations: The teacher's guide for the Science Centre 'Escola de Ciências, Biologia, e História'

Fig. 8.3 Science Centre visit: Escola de Ciências, Biologia, e História (School of Science, Biology, and History)

students visited the Escola de Ciências, Biologia, e História (School of Science, Biology, and History) (Fig. 8.3) located in the municipality of Vitória, in the state of Espírito Santo, Brazil. This Science Centre aims to democratize science and enable the population's access to knowledge on the ecosystems and historical heritage of Espírito Santo in a playful and interactive way. Its main mission is to express local culture and identity by discussing natural and cultural aspects of Ilha de Vitória (Vitória Island). There is an emphasis on the construction of the island's geographic space and also on the deterioration of local ecosystems along its historical path, in line with the construction of the country's history. The building where the Science Centre is located contains two floors. The first floor consists of an auditorium used to receive visitors. In this place, the students of the discipline had a lecture about the centre. On the second floor there are models of the regional historical heritage; archaeological artefacts that prove the existence of prehistoric populations in the region and elements of local identity; and a mockup of Vitória. Thus, it is evident that the Escola de Ciências, Biologia, e História has interdisciplinary characteristics involving knowledge that can contribute to environmental education and cultural recovery.

In the class after the visit, the students read the text of the problematic scenario about the space visited in the previous class, which also required virtual visits to online interactive museums, carried out in the computer lab. Soon after, they formed 3 groups of 5 students. The teacher started the next class with a dynamic to reflect on

Fig. 8.4 Group dynamics: the web of life versus the web of knowledge

the group work, called Ecological Web, comparing an ecosystem web of the Atlantic Forest with the web of knowledge. Students were asked to stand in a circle and name a biotic or abiotic factor in the Atlantic Forest ecosystem and throwing the ribbon to another person, who needed to name another biotic or abiotic factor related to the aforementioned factor, explaining the relationship. After the formation of the web, the teacher began to interfere by simulating a hunter and then the pollution of water resources. When they observed that every factor influences the others, the teacher asked them to reflect on group work, on the importance of having a web of knowledge, and on the interdependence of these elements to perform teamwork well (Fig. 8.4).

PBL Scenario 2—Field Trip

Scenario 2 aimed to work on the concept of environmental education. The activities developed are summarized in Table 8.2.

In the first class, the students were invited to play the Brazilian equivalent of the Go Green edition of Monopoly that exists commercially in Brazil, namely *Banco Imobiliario Sustentavel*. This game is the sustainable version of Monopoly with great emphasis on sustainability issues, in which the materials that make up the game like the pieces, which come from sugar cane, are highlighted. The game is based on the purchase of sugarcane producing regions and forest reserves with carbon credits (Fig. 8.5). After the playful activity, the teacher read Scenario 2: The *Banco Imobiliario Sustentavel* Game. Then the students got together in two groups to compare the two commercial games: *Banco Imobiliario Sustentavel* and Monopoly.

Table 8.2 Scenario 2 presentation cycle

Class number (h)	Activity
4	– *Banco Imobiliario Sustentavel* Game application – Scenario Reading: *Banco Imobiliario Sustentavel* – Collective elaboration of the problem questions on the board – Formation of groups
4	– Field trip: Vale Botanical Park
4	– Reading and discussion of answers – Preparation of the final product: a board game with the principles of environmental education
4	– Application and validation of produced games
2	– PBL planning by groups
2	– PBL plan presentations and validations

Fig. 8.5 *Banco Imobiliario Sustentavel* application

The next class was a fieldtrip to the Vale Botanical Park in Vitória (Fig. 8.6), which has 33 ha and is the green belt of the Vale mining company. It is considered a space for leisure, environmental education, and, above all, a conservation unit in the Atlantic Forest, one of the most important forests in the country. The park is home to more than 140 species of trees, such as pau-brasil, jacaranda, and Ipe, in addition to wild animals such as possums, marmosets, and several species of bird that can be seen on five ecological trails available to visitors. The park also has an orchidarium, a sensory garden, exhibition areas, and a library. The park offers buses to visit the interior of Vale's industrial complex.

Fig. 8.6 Fieldtrip: Vale Botanical Park

In the field class, students had the autonomy to respond to a field guide during the following activities: in the open part of the park, observe and get to know the selective collection carried out on site; in the sensory garden, observe and perceive the characteristics of the plants related to the 5 senses; on the trail, understand the process of environmental restoration and habitat fragmentation in the Atlantic Forest; and in the industrial area, know the main stages of the pelleting process.

After the visit, the students gathered in the classroom to read and debate the answers on the PBL monitoring sheet. The teacher ended the debate with a dialogued expository class on the different concepts of environmental education. At the end of the class, the students gathered in groups again to prepare the final product, which was a board game with social-environmental issues. In the last class, the students delivered the games and each group "played" the game made by the other group.

Instrument

For data collection, methodological triangulation was applied using different instruments and techniques (Table 8.3). The teacher-researcher, through the classroom diary, made an assessment of the process in the relevant aspects of student motivation, participation, group functioning, and difficulties and limitations with the

Table 8.3 Instruments and data collection techniques

Instrument	Data collection technique	Data analysis technique	Objective
Classroom diary	Observation	Content analysis	Describe the intervention program
Scenario products (Scenarios 1 and 2)	Inquiry	Content analysis	Assessment of Scenario 1 and Scenario 2 products for the three pillars of sustainability (economic, environmental and social)
Focus group (Scenario 2)	Inquiry	Speech analysis	Evaluation of games produced as the final product of Scenario
Questionnaire	Inquiry	Content analysis	Investigate PBL plan validation

adopted methodologies. To assess the contributions of the PBL methodology to environmental education, the final product of Scenario 1, the Teacher's Guide made by the students, was evaluated for the presence of the three pillars of sustainability (economic, environmental, and social) [19]. A focus group was formed during class to evaluate the final product of Scenario 2, which was a board game with the theme of sustainability. The focus group is a non-directive group discussion technique, which brings together people with certain common characteristics or experience to discuss a topic or area of interest. Focusing on a certain subject, the discussion does not seek consensus, but raises different opinions, attitudes, thoughts, and feelings, expressed verbally or otherwise, in a relatively short time [20].

Because the sample size was small ($n = 15$), descriptive statistics were used to verify the frequency of questionnaire responses. Scenario products were subjected to content analysis [21] by identifying units of analysis, in this case, phrases that reveal certain ideas in categories and subcategories [22].

We also sought to present the ideas expressed by the students, through the inclusion of full or partial lines, chosen according to the researcher's assessment of their relevance. The focus group was analysed to understand the real discourse through the central ideas and anchorages, using the discourse analysis technique [23]. Thus, the study sought to carry out a combination of analyses, using methodological triangulation, to interpret the results obtained from the intervention program.

Results and Discussion

Scenario 1 Analysis: Teacher's Guide

The students produced a "Teacher's Guide" for use in the space visited in Scenario 1 (Escola de Ciências, Biologia, e História), which was analysed from the perspective of interdisciplinarity and environmental education. Three guides were produced and analysed. A content analysis was carried out on the guides in order to find evidence of the three pillars of sustainability. These perspectives were also classified into subcategories, according to what was found in the students' scripts (Table 8.4).

The results point to an integration of the three pillars of sustainability content in all the guides developed by the students. As the mission of the Science Centre is to express the local culture and identity from the natural and cultural aspects of Ilha de Vitória, we believe that the very design of its exhibitions helped students in the construction of interdisciplinarity guides focused on the perspective of socio-environmental issues.

Scenario 2 Analysis: Game for Environmental Education

The games made by the students of the discipline, as the final product of Scenario 2, were also analysed for the presence of the three pillars of sustainability, in addition to analysing the game in terms of pedagogical aspects.

Group 1 made a board game entitled "Sustainability" (Fig. 8.7) containing a board, a dice, five pieces of animals from the Brazilian forest (armadillo, frog, snake, macaw, and toucan), and several cards. The objective of the game is to follow a path in the state of Espírito Santo on a trail made with figures representing companies and aspects of culture and the environment in that state of Brazil.

Group 2's game (Fig. 8.7) was entitled "Sustainable Attitude" and was made up of a board, a dice, four carts, several cards, several paper CO_2 molecules, and several paper trees. The objective of the game is to contribute to the environment by removing as many CO_2 molecules from the atmosphere as possible, which happens with every sustainable attitude of the player, who contributes by planting trees. For every six CO_2 molecules removed from the atmosphere, the player earns the right to plant a tree. The player who plants the most trees wins the game.

The games were evaluated though group debate, in which all the students were able to express and debate their opinions. Table 8.5 was used, with Yes and No, to categorize the results of the evaluation of the games regarding the level of agreement of opinion among the participants. Thus, Yes shows that everyone agreed with a positive answer, the No shows that everyone agreed with a negative answer, and the Yes/No shows that there was an impasse and a disagreement between the participants.

As for the didactic performance, the two games were evaluated as a pedagogical practice that contributes to the teaching and learning of scientific concepts, without

Table 8.4 Three pillars of sustainability analysis

Category	Subcategories analysed in the guides	G1	G2	G3
Economic	– Presents the place as fun and educational – Describes the conditions of the physical structure and location of the place – Presents the mission of the place in dealing with the historical heritage of ES – Presents the historical heritage of ES – Presents a tour guide that values the tourist centre of Vitória – Presents the model of the city of Vitória	X X X X X	X X X X X	X X X X
Environmental	– Presents the exhibition of Restinha, Mangrove, and Atlantic Forest ecosystems – Presents the site's mission to disseminate knowledge on the ecosystems present in ES – Presents citizenship training from an environmental education perspective – Presents a visit itinerary that focuses on the characteristics of the mangrove ecosystem and the implications of the capture and commercialization of the Uçá crab – Presents a visit itinerary that deals with the concept of ecosystems and the characteristics of ecosystems present in ES – Presents the possibility of working on the degradation of ecosystems due to population growth – Presents the landfill areas and the green areas in the Vitória model	X X X X X X X	X X X X	X X X X
Social	– Presents the mission of the place in expressing the local culture and identity – Presents cultural rescue and social inclusion – Describes the diversity of possible pedagogical scripts for educational action – Presents the archaeological sites and the possibilities of working on prehistory and its relationship with the present – Presents the space's creation story – Presents the integration of nature and culture to talk about the identity of the city of Vitória – Presents the possibilities of also working with knowledge such as art and/or literature	X X X X	X X X X X X X	X X X X X X
Interdisciplinarity	– Presents interdisciplinarity	X	X	X
Three pillars	– Presents articulation between the three pillars of sustainability	X	X	X

(a) Group 1 Game: "Sustainability" (b) Group 2 Game: "Sustainable Attitude"

Fig. 8.7 The games made by the students of the discipline, as the final product of Scenario 2

Table 8.5 Focus group work inquiry to validate the games produced by students

Game evaluation	G1	G2
Didactic performance	Y	Y/N
(1) Are the rules clear? Is it easy to understand and play?	N	N
(2) Are there any conceptual errors?	Y	Y
(3) Does the game contribute to teaching and learning scientific concepts?		
Sustainability assumption	Y	Y
(4) Does it encourage critical thinking by the students?	Y	Y/N
(5) Does it stimulate reflections on the social and environmental problems generated	Y	Y/N
by capital?	Y	N
(6) Can the game articulate the 3 pillars of sustainability - Economic, Social, and Environmental?		
(7) Does the game have social and environmental responsibilities for various actors (individual, collective, public policies)?		

Subtitle: Y = Yes; N = No; Y/N = no consensus

presenting conceptual errors. The Group 1 game rules are based on those of a regular board game, so they are relatively clear and the game starts easily. The rules of the Group 2 game, however, are not so clear, and require careful reading of the game manual. Despite being more complex in terms of rules, the Group 2 game proved to be much more creative and innovative.

As for the assumptions of socio-environmental issues, we observed that the two games meet the expectations of stimulating the student's critical thinking. However, the Group 2 game did not fully achieve the objective of stimulating social reflection and therefore one of the pillars of environmental education was not well incorporated into the rules of the game. This is because the Group 2 game does not have several social actors with socio-environmental responsibilities, with the expected changes being focused only on the individual behaviour of students.

According to Edgar Morin [5] the vision of the whole and the parts needs to be worked on in order to achieve a glimpse of the complexity of reality. Environmental education needs to be focused on the problematization experienced and also on the recognition of nature's relationships with social groups and the "place" occupied by these in society. This reflection seeks new syntheses that indicate new democratic, sustainable, and fair paths for all.

PBL Plan Validation

At the end of the intervention program, the students planned a PBL scenario to be applied in a non-formal education space. **PBL 1** was "Hair-raising!", to be applied in the Escola da Ciência-Física (School of Science and Physics) Science Centre, located in Vitória, ES, Brazil; and **PBL 2** was "Garbage: An everyday problem", to be carried out as a field class at the "Marca Ambiental" landfill, located in Cariacia, ES, Brazil.

The "Hair-raising!" scenario was developed for 9th grade elementary school students and had the following objectives: make students observe the concepts of types of electrification using the Van de Graff generator; explain the small shocks we take in everyday life through electrostatics; differentiate conductors from electrical insulators; and understand how a material can be electrified. The final product proposed was to develop experimental activities that demonstrate the types of static electrification (contact, induction, and friction) and relate them to real everyday situations.

At the end of the "Hair-raising!" presentation, the group that was watching commented that the scenario lacked an interdisciplinary and socio-environmental perspective, as the focus was on the conceptual contents of the discipline of physics. There were even suggestions for working with lightning and thunder from the perspective of damage to the environment, the dangers of a person being hit, and the precautions that should be taken.

Students filled out a Scenario Plan Validation Questionnaire for "Hair-raising!" and the results are shown in Table 8.6. During the validation of the plan, it was evident that some adjustments were needed to contemplate the interdisciplinarity and socio-environmental issues relevant to environmental education, as shown in the speeches of the subjects (S) below about using this scenario in their classes.

S1: "Yes. However, I would try to promote greater interaction between disciplines."
S2: "Yes. In an articulated way, not focusing only on conceptual content."
S4: "The theme could have been addressed in a more creative and interdisciplinary way."
S5: "I couldn't see other subjects in the PBL presentation, I only noticed physics and biology."
S6: "The topic has the potential to address the socio-environmental issue, but it was not focused on."

The "Garbage: an everyday problem" scenario was developed for 1st year high school students and had the following objectives: to relate the impact caused on the

Table 8.6 PBL planning validation

PBL planning	PBL 1 "Hair-raising!"					PBL 2 "Garbage: an everyday problem"				
Category	1	2	3	4	5	1	2	3	4	5
Theme (contextualization)	0	0	2	3	3	0	0	0	1	4
Curriculum contextualization	0	0	0	2	6	0	0	0	0	5
Time	0	0	0	3	5	0	0	0	3	2
Prerequisites	0	0	2	0	6	0	0	0	2	3
Specific objectives	0	0	2	2	4	0	0	0	3	2
Disciplinary articulation	0	2	4	2	0	0	0	0	1	4
Concepts	0	0	1	4	3	0	0	1	1	3
Scenario	0	0	1	5	1	0	0	0	1	4
Sustainability perspective	0	1	3	3	1	0	0	0	2	3
Articulation with formal and non-formal education	0	0	0	1	7	0	0	0	0	5
Survey of problem-questions	0	0	0	1	7	0	0	1	1	3
Final product	0	0	2	2	4	0	0	0	2	3
Data source	0	0	1	2	4	0	1	0	1	3
Tutorial cycle steps	0	1	1	5	1	0	0	0	2	3
Application	0	0	3	3	2	0	0	0	1	3
Evaluation proposal	0	0	2	5	1	0	0	1	3	1
Originality of the PBL proposal	0	0	4	3	2	0	0	3	1	1
Clarity and intelligibility of the proposal	0	0	2	4	2	0	0	0	2	3

environment by inappropriate waste disposal; understand that the waste produced can be reused; relate the issue of waste production reduction and consumption control; relate soap production to chemical transformation processes; and raise awareness in the school community about the production, disposal, and reuse of waste. The disciplinary articulations involved Biology, Chemistry, Sociology, Physics, and Portuguese Language. The final product was the production of documentary videos on the consumption and reuse of waste. At the end of the scenario presentation of "Garbage: an everyday problem", all the students who were watching expressed satisfaction with the proposal. This plan works the conceptual contents within an interdisciplinary perspective and explores the relevant socio-environmental issues of environmental education, as pointed out in the speeches of the subjects (S) below, when asked if they would apply this plan in their educational context.

S7: "Yes. Throughout the year in an interdisciplinary way involving the environment and health."

S8: "Yes. I could use it to talk about the waste produced by the mining sector."

S9: "Yes. Because it is relevant and enhances socio-environmental issues, allowing for articulation with other disciplines."

S10: "Yes. Because the proposal presented is relevant and constituted in a cohesive and conscious way."

S11: "Yes. Due to coherent planning and relevant themes."

S12: "Yes. The work made the great concern with socio-environmental issues very clear at all times."

As for the negative aspects, only the assessment that focused on conceptual knowledge was mentioned.

Thus, in the analysis of the two PBL scenarios elaborated by the research subjects, the plan of the "Garbage: an everyday problem" scenario group managed to achieve all the goals. However, even the IP did not guarantee the break with the paradigmatic conceptions of traditional teaching in the plan of the "Hair-raising!" scenario. We believe the fact that the chosen science centre, the Escola da Ciência-Física, still has characteristics of disciplinary fragmentation, contributed to this result.

Conclusion

We found that applying the PBL methodology to Scenario 1 and Scenario 2 enhances the development of skills such as critical thinking, argumentation, writing, communication skills, teamwork, and the search for solutions to problems and promotes the collective construction of knowledge. It was evident that the methodology was well accepted to be applied in different degrees of academic training, be it elementary, secondary, or higher education.

The results also lead to the conclusion that, when applied to spaces of non-formal education like Science Centres and field trips, PBL enhances distinctive features of teacher training (such as a privileged space for reflecting on education, its complexity, and the possibilities of interdisciplinary teaching practices), in addition to favouring the acquisition of knowledge that will promote attitudes concerned with sustainable education, which are much needed features in this new epoch, the Anthropocene.

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Chapter 9
Living Labs in Higher Education: Sustainable Buildings Technologies

Carlos Afonso Teixeira, Anabela Paiva, Isabel Bentes, and Jorge Pinto

Abstract Sustainable development is today's big challenge that we need to overcome in order to assure well-being and resources for future generations, and at the same time protect ecosystems and guarantee biodiversity. Circular economy seems to be a key tool to slow down the environmental degradation of the planet. Implementing circular economy requires a general participation, which includes citizens, industry, companies, organizations and politicians. Each part has a relevant role in this process which goes beyond their role as being creative, innovative, technology creator, planning manager or politician. This way it is possible to form networks and experts able to solve real problems. Universities are fundamental in terms of knowledge, innovation, creativity and technology development and they have all the conditions to work as living labs. They give a significant contribution in terms of teaching and disseminating sustainability and also circular economy. In this context, Universidade de Trás-os-Montes e Alto Douro (UTAD) has been pioneer because the sustainability of cities and, in particular, sustainable construction have been taught and researched for a long time. In fact, UTAD, as a living lab, has played an important role worldwide concerning the study of the Tabique as a sustainable traditional Portuguese building technique. Thus, this chapter presents a view of sustainable

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construction, the role of the universities as living labs and the Tabique as a study case of sustainable building techniques in a living lab perspective.

Keywords Sustainability · Circular economy · Living lab · Sustainable construction · Tabique

Introduction

A Living Lab aims to increase innovation through the creation of innovative projects involving different stakeholders, especially its users, and which includes experimentation in real environments. It can have a physical place, but one of its characteristics is that it is mobile and alive because it is made of people rather than places and technologies.

Universities and research centres are the most important centres for research and innovation, bringing together scientists from various fields of knowledge, which facilitates the creation of integrative projects, in addition to being innovative. When universities manage to bring together in these projects several stakeholders, they constitute living labs capable of contributing decisively to the generation and dissemination of new concepts and new technologies, in the promotion of new business relationships and in the exchange of new knowledge.

One of the biggest challenges facing human kind today is the sustainability of the planet and, therefore, the ability to implement a circular economy. Sustainable practices depend on awareness of institutions, associations and citizens in general, but their adoption is still very incipient. However, this awareness by itself is not enough, it needs to be accompanied by technical, technological and support instruments for its adoption. The existence of live laboratories in this area can make a very assertive and effective contribution to the implementation of sustainable practices.

The University of Trás-os-Montes and Alto Douro (UTAD) has extensive experience in research and teaching in the field of climate change, sustainable development and circular economy.

Based on these principles for research and teaching, UTAD developed projects in the areas of sustainable construction, urban planning and use of natural materials, local materials, new materials using waste and in the preservation of traditional building systems, among others, that lead to lower environmental impacts.

This investigation/teaching materialized in the creation of a living laboratory on the UTAD campus where the study and preservation of the Tabique wall, a traditional construction technique that uses natural and local materials, is a successful project that will be described later on in this chapter.

Sustainable Construction

In 2050 will be expected that three quarters of the world's population will live in cities. In the current context of linear take-make-waste economy, urban centres consume more than 75% of natural resources, produce more than 50% of waste and emit between 60 and 80% of greenhouse gases [1, 2]. The contribution of cities to resource depletion and environmental degradation is very significant. It is urgent to change this situation, involving all citizens. This will only be possible with the alignment of public policies, with the increment of innovation, with the availability of financial and communication instruments. This change will tend to modify housing model, citizen mobility and economic development in line with the 2030 Sustainable Development goals. These include reducing greenhouse gas emissions and adapting to the effects of climate change.

Cities, where most materials are used and wasted, and where buildings, cars and products are consistently underused, should lead this transition, leaving behind the linear economy and adopting the circular economy based on the principles of reduction, reuse, recovery and recycling materials and energy. The urban areas will lead this transformation, given that 80% of food will be consumed in cities by 2050 [3].

The circular economy offers the opportunity to rethink the way we make and use what we need, by postponing the end-of-life concept, introducing new circular flows of reuse, recycling and renewal. The transition to the circular economy allows exploring new ways to ensure long-term prosperity through the efficient use of resources, mobility and sustainable economic development.

The implementation of the circular economy in cities, integrating businesses, public entities, organizations, institutions, communities and citizens, can bring enormous economic, social and environmental benefits. To achieve this, a great deal of awareness and involvement of all is needed, and the role of universities in the search for technical solutions, their dissemination and mind-set changes will be crucial.

The Role of Universities

The Universities' commitment to environmental education is very important and the campuses must be living laboratories, where technical solutions are developed, economic, social and educational strategies are studied, allowing progress towards the best environmental practices. University and Polytechnic Education Institutions should promote the development and dissemination of good environmental practices, in the context of the academic training of their students, as well as to constitute themselves as privileged spaces for development activities, projects or other programs in favour of the environment [4, 5].

The environment and sustainability are concepts that are bigger than recycling, saving water, reducing energy costs and protecting nature. International organizations consider sustainability as an instrument for social integration, efficiency and environmental enhancement. At the university level, sustainability must be an identity and aggregating element for the entire academy. Universities must also have the capacity to interact with external agents, namely, economic and political, in order to be able to make a relevant contribution in the transition to the circular economy.

The construction of sustainable cities is only possible with the application of the Circular Economy principles. Thus, it is necessary to discuss what new circular economy brings, especially to regions and urban areas, and to lay the foundations for institutional, business and educational cooperation in order to promote a transversal change in society. The materialization of this vision will make cities more productive, places where the economy grows by eliminating waste and reducing operating costs of ecological systems, mobility and urban services. This will also make air quality and urban health improve considerably, reducing carbon emissions and pollution in cities. Thus, cities will be more resilient, keeping materials in use, reducing consumption pressures and encouraging local production and distribution.

Living Labs at Universities

The Living Labs philosophy is based on teaching and participation of Stakeholders interested in scientific developments carried out or in progress at higher education institutions. This allows innovation, promotion and testing inventions and solutions that the Universities themselves research and teach. Its materialization gives higher education institutions the ability to use their campuses as living laboratories open to external audiences. Scientific interaction in a more relaxed environment facilitates the interface of scientific developments with the outside world by creating areas of innovation and enhancing synergies to achieve common goals.

Living Labs respond to new Environmental Education paradigms by engaging the most dynamic parts of society for environmental sustainability. They will be decisive in demonstrating, for example, construction solutions that reuse existing resources in the regeneration and rehabilitation of urban systems and infrastructures. The creation of circular societies requires new assumptions, namely in the involvement and collaboration between the different stakeholders in urban planning and in the defence and promotion of the environment. Catalysing this cooperation, understandings about the importance of the Environment in society are enhanced.

The relevance of Living Labs in sustainability lies in Enhancing Environmental Education through Nature-based solutions, simultaneous integrating research, teaching (supported by research carried out) and demonstration in the field of climate change, sustainable development and circular economy.

1. **Climate Change**. Livings Labs can teach how to fight climate change through close cooperation with international partners to further cut emissions by at least

55% by 2030 [6]. Once by 2050, Europe aims to become the world's first climate-neutral continent teaching focus should put on the EU climate action and the European Green Deal to reduce greenhouse gas emissions, to invest in cutting-edge research and innovation, to preserve Europe's natural environment.

2. **Sustainable Development**. The 2030 Agenda for Sustainable Development [7] and its 17 Sustainable Development Goals (SDGs) [8] are committed to eradicate poverty and achieve a sustainable world by 2030 through human well-being and a healthy planet.

The 17 sustainable development goals (SDGs) are:

- GOAL 1: No Poverty
- GOAL 2: Zero Hunger
- GOAL 3: Good Health and Well-being
- GOAL 4: Quality Education
- GOAL 5: Gender Equality
- GOAL 6: Clean Water and Sanitation
- GOAL 7: Affordable and Clean Energy
- GOAL 8: Decent Work and Economic Growth
- GOAL 9: Industry, Innovation and Infrastructure
- GOAL 10: Reduced Inequality
- GOAL 11: Sustainable Cities and Communities
- GOAL 12: Responsible Consumption and Production
- GOAL 13: Climate Action
- GOAL 14: Life Below Water
- GOAL 15: Life on Land
- GOAL 16: Peace and Justice Strong Institutions
- GOAL 17: Partnerships to achieve the Goal.

3. **Circular Economy**. The European Commission Circular Economy Action Plan it is the strength point of Europe's new agenda for sustainable growth. The Action Plan focus on the entire life cycle of products, targeting for example their design, promoting circular economy processes, fostering sustainable consumption, and aiming to ensure that the resources used are kept in the EU economy for as long as possible [9–11]. The higher education Living Labs should enforce measures to Make sustainable products; Empower consumers and public buyers; sectors that use most resources and where the potential for circularity is high such—electronics and ICT; batteries and vehicles; packaging; plastics; textiles; construction and buildings; food; water and nutrients—Ensure less waste; Make circularity work for people, regions and cities; and lead global efforts on circular economy.

The higher education institutions are well placed to promote the sharing and dissemination of research in the fields of Sustainable Development, Climate Change and Circular Economy (Fig. 9.1). The knowledge acquired in these domains is taught through classical teaching models or through technical training methodologies and

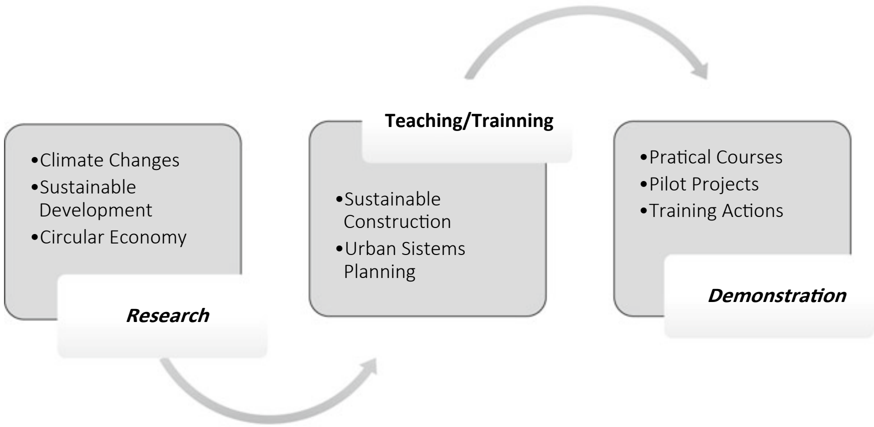

Fig. 9.1 Nature-based solutions living lab's framework

its practical demonstration takes place in the form of practical courses, pilot projects or training and demonstration actions more or less formal.

The knowledge acquired through research projects enable the higher education to consolidate key concepts and anticipate challenges and opportunities for cities. The scientific knowledge acquired ensures practical and laboratory teaching aimed at experimentation related to the design of products and planning of sustainable urban systems. The dissemination actions and demonstrations are thus more accessible to Stakeholders of the transition to cities and regions and circular territories in the sectors of urban planning, construction and urban systems and dematerialization.

A Living Lab stimulates, organizes and articulates the passive participation of the public (e.g., exhibitions, teaching materials, practical digital guides, sustainability plans, conferences/seminars) through the promotion of training actions, transversal courses in bachelor's and master's degrees and organization of technical-scientific dissemination seminars. Students can interact with Stakeholders and discuss these principles in city planning and in the design of urban systems based on sustainable construction, showing success stories in the efficient use and rehabilitation of buildings.

The training takes on a dynamic and transversal nature in which discussion and debate focus on understanding how circular cities can trigger the transition to a system in which, in addition to reducing waste, the very concept of "waste" is eliminated. Practical courses, pilot projects or training actions can focus on how to design durable, adaptable, modular and easy to maintain and redirect infrastructures, buildings and products in the face of sustainability challenges. Test new materials and construction methods to allow repair and reuse and reduce waste, or new techniques to ensure greater incorporation of local products—both reclaimed and reused—to reduce transport and storage needs. The potential to demonstrate how to apply locally sourced products without meaning loss of value, while simultaneously helping to regenerate natural systems in and around cities are enormous. Another important aspect is the demonstration of cities with more efficient use of energy and water and the reuse and recycling of materials already in use.

The transformation of the higher education institutions Campuses into Living Labs must be accompanied by demonstration and application actions in the field of sustainable construction having in mind the dissemination of knowledge on sustainable development, adaptation to climate change and the circular economy in a pragmatic and relaxed way. Every effort is made to promote new methods, materials or construction systems based on the reuse or valorisation of endogenous products, where the valuable materials remain in use through several evaluation cycles. Thus, cities increase their resilience through the supply of resources, diversifying suppliers (local and global) and relying on raw materials obtained in peri-urban areas.

Tabique as a Case Study of Sustainable Construction

Tabique construction is a traditional building technique applied worldwide. It is an interesting solution because it mainly uses raw and local building materials such as earth and timber. This building technique is quite important in the North of Portugal, in particular, in the Trás-os-Montes e Alto Douro (TMAD) region which most of the heritage includes Tabique building elements [12–14]. It was noticed that there was a lack of scientific studies concerning this technique. In fact, in the Portuguese building industry, there has been a paradoxical situation because the owners and the building contractors have been encouraged to maintain and to rehabilitate but, on the other hand, there are yet a lack of practical technical procedures to guide these kind of works. Unfortunately, the demolition of timber and Tabique elements in old buildings is still a reality. In order to change attitude, several works were developed since 2009 about Tabique construction. Nine master thesis and one PhD thesis are some of works that are reference in terms of surveying the Tabique construction in this region and in terms of characterizing materials and buildings. At this stage, the main goal was to highlight the relevance of this type of traditional construction, to valuate it and to alert for the destruction that was happening related to this heritage. In order to achieve this goal, several chapters of books, papers in journals and papers in conferences have been published.

Tabique construction started to be a topic that is part of courses of high level degrees. For instance, building materials, timber structures and conservation and rehabilitation of buildings are some examples of courses that are part of the civil engineering degrees such as bachelor and master degrees, of the Trás-os-Montes e Alto Douro (UTAD), in Portugal. At the same time, some events such as seminars, summer schools and workshops have been done in this region, in order to share with the community, the relevance of preserving this type of heritage. In addition, in a more scientific context, the main achievements obtained by the research of Tabique by 2017 were presented and discussed in the Ciência 2017 event. We are very proud to state that UTAD has been pioneer concerning the study of Tabique

Fig. 9.2 Example of a two floors Tabique dwelling of this region

construction. During almost 20 years of research some important results have been achieved concerning this type of construction.

Based on the surveying done about the existing Tabique construction in TMAD region [15–18] it was concluded that dwellings of two floors may be the most common building solution. Figure 9.2 presents an example of this solution in which it is possible to figure out that the Tabique walls are built on the first floor. At the ground floor, schist masonry walls were adopted instead of Tabique walls in order to increase the durability of the construction. This is a common feature concerning this type of construction in this region. In fact, the building in Fig. 9.2 is an earlier example of a Tabique building of a rural area of this region.

These kind of Buildings were mapped in several parts of this region. The buildings were characterized in terms of function, conservation level, number of floors, location of Tabique building elements, type of exterior revetments, among other technical aspects. The Tabique construction uses raw, natural, local and reusable building materials. Therefore, it seems to have a good sustainable performance as a building system. The main building materials are earth and timber, Fig. 9.2. However, straw and corncob are other materials that can been used in this building technique, Fig. 9.3.

Part of our research has been focused on the characterisation of these materials, in particular, the earth applied in the revetment of the Tabique walls. In this part, UTAD campus as a living laboratory has been a key facility because the local earth of the campus has been tested and used as a building material for Tabique wall models. In addition, the Materials and Soil Lab, the Electronic Microscopic Unit and the Forest Products Lab of UTAD have been also used in this part of the research. On the other hand, teaching these topics concerning Tabique construction is also a very important task in this process. Therefore, university regular lectures and events such

(a) (b)

Fig. 9.3 Straw and corncob as building materials of Tabique walls. **a** Straw, **b** Corncob

as seminars and international summer school (Fig. 9.4) have been used to achieve this goal.

In terms of structural aspects, the Tabique walls are also very interesting among the traditional vertical structural building elements perspective. In fact, they may work as an alternative of stone masonry walls and as a lightweight solution. They are included in the traditional timber structural elements. They can be either exterior or partition walls. They tend to be placed in the upper flowers as a durability precaution. They can have different thicknesses and different structural constitution. They can be single or cavity. The simplest structural constitution solution is a regular frame

(a) (b)

Fig. 9.4 International summer school 2018—UTAD. Aldeia de Uva. Portugal. **a** Teacher applying revetment, **b** students and teacher observing of vertical rough timber elements linked to each other by horizontal slats which are nailed, Fig. 9.3b.

UTAD has been a pioneer in the physical characterization of Tabique walls. Several works have been performed in the UTAD campus as a living laboratory. For example, thermal behaviour of filling of Tabique wall (Fig. 9.5, diagram of the right side) has been tested [19] and also fire resistance of Tabique walls (Fig. 9.5, left side, [20]). In both situations, the experimental results were very promising and they converge for the suitability of the traditional Tabique walls for the current standards.

We believe that our goals concerning preserving Tabique elements have been achieved gradually because people have been more aware about their value has a building element. Thus, our research and our teaching in a living laboratory as UTAD has proved worth in this topic. For instance, in case of Fig. 9.6a, the owner of the dwelling kept the original Tabique walls. The impressive 5.90 by 2.60 m Tabique

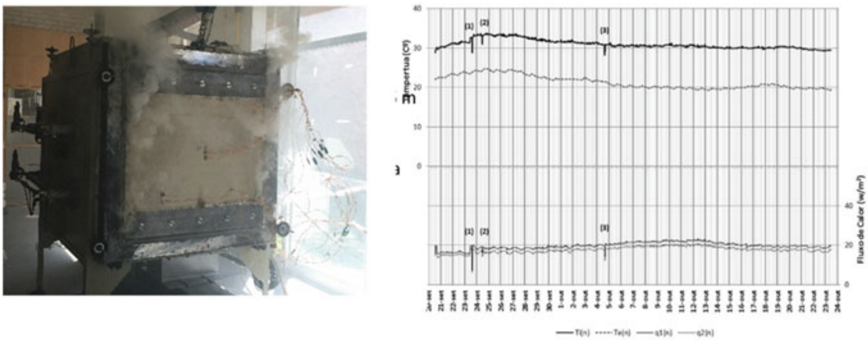

Fig. 9.5 Some physical tests of Tabique walls

(a) (b)

Fig. 9.6 Examples of antique Tabique walls. **a** Partition wall, **b** bathroom Tabique wall

wall was remained as it has been for more than one hundred years. On the other hand, in the case of the Tabique walls of Fig. 9.6b, they were also preserved. Taking into account that they are placed in the bathroom they were covered with white ceramic tiles in order to improve their waterproof. As it is possible to see from this figure, it was possible to coat these traditional building elements with new materials.

Tabique is a valuable heritage of Trás-os-Montes e Alto Douro region. It is also a sustainable building solution model. It is still necessary to improve the surveying of Tabique construction in this region and also to prepare a detailed inventory about this heritage. Meanwhile, the research results, show that Tabique construction is very promising and it is quite impressive to realize that Tabique elements more than 100 years old may verify the recommendations of the current standards. People have gradually been sensitized to the value of the Tabique building elements. Thus, the UTAD campus as a living laboratory has proved to be efficient in this issue both in researching and disseminating information.

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Chapter 10
What is Latin America Doing Regarding the Research and Teaching of Nature-Based Solutions (NbS) to Boost Environmental Education?

José Contreras, Ana María Leiva, Yenifer González, and Gladys Vidal

Abstract Nature-based solutions (NbS) emerge with the aim of facing the several different challenges imposed by climate change and the extreme conditions that humanity is facing. The main purpose of this study is to evaluate NbS related research and teaching in order to prompt environmental education in Latin America. As a means to obtain information about the types of courses and undergraduate research and/or postgraduate training that has being done, investigation groups from Argentina, Brazil, Chile, Mexico and Peru were reached with the help of the Pan-American Constructed Wetlands Network (HUPANAM). This information was complemented with a Web of Science (WoS) review of Nbs publications in Latin America in 2010–2020. Within the study period 2010–2020, a total of 706 studies related to NbS were found in Latin America, being the groups in Brazil (319), Mexico (151), and Chile (83) the ones that led in the number of published research. Additionally, during the study period, an increase of 65% from 2010 to 2020 of publications in WoS could be observed due to the studies conducted by different researchers from Latin America. The most studied topics regarding NbS are constructed wetlands (CW) (38%), biofilters (23%), and stabilization ponds (16%). In terms of the promotion of environmental education related to NbS, a series of books, book chapters and courses can be found. For instance, the book "Constructed Wetlands: Design and Operation", the book chapter "Strategies of the constructed wetlands operation under the perspective of the global change scenario" and undergraduate courses and summer schools related to CW can be highlighted.

Keywords Nature-based solutions · Environmental education · Latin America · Sustainable development goals · Bibliographic review · Constructed wetlands

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Introduction

Currently, society is facing challenges related to extreme events because of climate change (e.g., floods risks and droughts) and rapid urbanization [1, 2]. Having in consideration the previously mentioned and in order to restore cities ecological flows as new solutions that increase resilience in the city, nature-based solutions (NbS) have emerged [3]. According to the European Commission (EC) [4], NbS are defined as "solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social and environmental benefits". Additionally, other definitions of NbS are provided in the literature, Albert et al. [5] defined NbS as "actions that (i) alleviate a well-defined societal challenge, (ii) utilize ecosystem processes of spatial, blue and green infrastructure networks, and (iii) are embedded within viable governance or business models for implementation". On the other hand, Maes and Jacobs [6] defined NbS as "any transition to a use of ecosystem services with decreased input of non-renewable natural capital and increased investment in renewable natural processes". NbS allow to present innovative uses of the existing ecosystems, such as the role of urban forests and street trees in adapting to climate change [7]. Furthermore, NbS attain human and ecological benefits granting sustainable solutions that allow, for example, the increase of the well-being, biodiversity, sustainable energy use, watershed management and actions such as the protection, restoration, and management of ecosystems and the promotion of environmental education [2, 8, 9].

Environmental education is a holistic lifelong learning process that have the objective to produce responsible citizens with a positive transformation of an individual's environmental ethics, environmental knowledge and environmental awareness, attitudes and behavior [10]. In North America, the concept emerges in the 1970s, bringing to light topics related to conservation in the school curriculum. Whereas in Latin America, environmental education began to gain popularity during the 1980s because of the action of non-governmental organizations with strong ties to social movements [11, 12]. Environmental education allows the creation of synergic spaces, facilitating opportunities for scientists, decision-makers, community members, and other interested members to converge. Moreover, thanks to environmental education, people are encouraged to interact with research, thus shedding light on local knowledge, experiences, and practices [13, 14]. Consequently, and given the fact that NbS are found to be at an early development stage in Latin America, higher education institutions, together with postgraduate studies, may play an important role in the development and dissemination of knowledge about NbS. Therefore, the aim of the current study is to examine what is being done in Latin America regarding teaching and research on NbS to promote environmental education in this region.

Material and Methods

Bibliometric Analysis

A bibliometric study of the papers related to NbS in Latin America was performed using Web of Science (WoS) database. For this, the keywords used for this analysis were by NbS: constructed wetland, green roof, buffer strips, street trees, green corridors, pocket parks, biofilters, biosequestration, green walls; by country: Mexico, Brazil, Chile, Argentina, Colombia, Costa Rica, Peru, Bolivia, Uruguay, Paraguay. The selection of the NbS mentioned above was based on the research published by Faivre et al. [9]. In this analysis the number of publications related to each NbS and each Latin America country between the period 2010–2020 were considered.

Information from Latin America Investigation Groups

For this section, information from different Latin America investigation groups were used. Through the Pan-American Constructed Wetlands Network (HUPANAM), the main groups from Argentina, Brazil, Chile, Mexico and Peru were contacted to obtain information about: the number of books and book chapters related to the different NbS selected; the number of undergraduate, master and postgraduate students and the types of training regarding courses related to NbS and environmental education that are being offered and conducted.

Description of Different NbS

NbS have been identified by the EC as relevant owing to the inclusion of the ecosystem's restoration (e.g., green roofs, green walls, or green derelict industrial sites), mitigation and adaptation measures, such as afforestation, natural flood control, and constructed wetlands (CWs) [15]. As an example, characteristics of different NbS can be found below. It is important to mention that the selection of NbS was based on the research published by Faivre et al. [9].

– **Biofilters**: The biofilters correspond to unconventional wastewaters treatment systems [16]. These systems are composed of abiotic components (plants/earthworms/microorganisms) and a support medium. This double condition favors simultaneously physical (sedimentation, precipitation), chemical (absorption, ion exchange), and biological processes (degradation, transformation, absorption) [17]. Biofilters can be used for wastewater treatment in homes and industries that do not have a public sewer system [16]. Previous research has concluded that they can reach chemical oxygen demand (COD) removal efficiencies of 91%, with an inlet concentration between 479–487 mg/L, and they are also capable of nitrifying, denitrifying, and eliminating between four and eight logarithmic units of fecal coliform (FC) [18].

– **Buffer strips**: Buffer strips are defined as land strips with permanent vegetation usually trees, bushes, and grass that are adjacent to water bodies such as lakes, streams, ponds, and nearby wetlands. These ecosystems are considered as a transition between land and water ecosystems and provide several ecosystem services [19]. Several different studies have concluded that buffer strips are capable of helping with various essential functions, such as filtering surface and underground flow, mitigating erosion in water bodies, improving the microclimate, reducing nutrient pollution to the aquatic environments (adhering and assimilating nutrients), and serving as barriers for pesticides, among others [19, 20].
– **Constructed wetland**: CWs are engineering systems used for industrial and domestic wastewater treatment. These systems employ natural processes that involve vegetation, substrate, and microorganisms and are characterized by low energy consumption, high performance, and easy operation and maintenance. This green technology is an alternative in decentralized areas with a population of < 2000 [21–23]. CWs are capable to reach removal efficiencies higher than 90% for COD and ammoniacal nitrogen (NH_4^+-N), with an inlet concentration between 146–148 mg/L and 62–75 mg/L, respectively [24]. Moreover, one of the characteristics that distinguish CWs from other types of final effluent treatment is the presence of macrophytes where the different life forms of aquatic plants gain great importance regarding their function in the treatment [25]. Since the 1990's CWs have had a significant increase around the world. Therefore, CWs are an interesting option to explore when considering developing countries [26].
– **Green roofs**: Green roofs have been adopted as a technological solution for sustainable development since they integrate vegetation into buildings to reduce to the minimum some of the negative effects of urbanization [27]. The vegetation used in green roofs is wide-ranging and includes grass, sedum, succulents, and bushes. Moreover, green roofs are applicable to extensive (6–15 cm of the substrate) and intensive (20–70 cm of the substrate) covers [28]. Among the benefits found in green roofs, it can be mentioned their capacity to collect rainwater (66% retention), pluvial flood risk reduction, roof temperatures reduction (around 42% of rooftops temperatures), air decontamination, reduction in energy consumption of buildings, and reduction regarding noise levels [27, 29, 30].
– **Green walls**: Green walls have been established as a way to improve the quality of life of urban environments [31]. They are technological systems consisting of vertical constructions cover with plants and all the elements that support their growth. Generally, green wall is the common term used to refer to all forms of vegetated wall surfaces. These walls are composed of climbing plants that grow on a wall without additional infrastructures (direct system), or with the use of stainless steel or wood lattice, mesh, or wiring as support (indirect system). It is important to mention that in this study, there are considered green wall in a general form [32]. Additionally, green walls are considered to be low-cost, sustainable,

and require minimum maintenance. Some of the benefits that green walls have, we can mention that they help mitigate the heat island effect, improve the air quality, reduce fine dust levels, promote rainwater retention, act as a barrier for acoustic insulation and reduce energy consumption regarding cooling and heating [33, 34].

- **Street trees**: Street trees are a sustainable measure that provides aesthetic beauty and visual relief in specific urban settings. Furthermore, they provide a variety of psychological, social, and economic benefits to residents and businesses [35]. Street trees increase the livability of town and cities by reducing stormwater runoff and flood risks. Additionally, they act as acoustic filters, improve air quality, store carbon and other pollutants such as ozone (O_3), oxides nitrogen (NO), sulfur oxides (SO_3), sulfur dioxide (SO_2), carbon monoxide (CO), carbon dioxide (CO_2) and particles smaller than 10 μm in size; provide energy savings in the building, shade, and reduce surrounding temperatures and mitigate the urban heat island effect [36]. Also, they improve biodiversity by providing food, habitat, and landscape connectivity for urban wildlife [37].
- **Stabilization ponds**: Stabilization ponds are characterized as an alternative for wastewater treatment particularly in small cities, towns, and regions with big areas of land since they are conceptually simple systems, highly efficient, low cost, low maintenance, and solid systems for wastewater treatment and reuse [38]. In stabilization ponds, organic matter and nutrients are removed through biological, physical, and chemical processes, and due to the interaction of bacteria and suspended algae [39]. Furthermore, among the benefits of stabilization ponds is that water can be reused for irrigation, which brings social, economic, and environmental benefits [40].

General Overview of NbS

Globally there have been different initiatives focus on the implementation of NbS, such as, The Paris Agreement (2015), The New Urban Agenda (2016), the Sendai Framework for Disaster Risk Reduction, The United Nations (UN) agreement on biological diversity regarding the restoration of biodiversity, climate change and the integration of biodiversity, in bilateral cooperation (UE-China Urbanization Association) [41–44]. All of these initiatives have emphasized the importance of including the ecosystem protection in urban and territorial planning and related it with important topics such as climate action, disaster risk reduction, circular economy, biodiversity protection and health security [4, 9, 45]. Likewise, the Sustainable Development Goals (SDG) were emerged in 2015 during the 2030 Agenda, which are a set of objectives, goals and indicators in the areas of poverty reduction, environmental protection, human prosperity and peace [46].

Regarding the different NbS, several studies discuss the effects of their implementations for remediating different environmental problems. For example, Liquete et al. [47] developed a series of CWs surrounded by a park in Gorla Maggiore (Italy) in order to treat sewer overflows. The deployment of CWs was able to absorb 71% of the affluent volume. Additionally, it presented removal efficiencies of organic matter and NH_4^+–N between 72 and 96% and allowed for the creation wildlife and recreation instances. Moreover, Todorov et al. [48] evaluated a green roof for its ability to retain precipitation water on a commercial building in New York, USA. In their study, they concluded that the green roof was able to retain on average 95.9% per rainfall event with a range of 75 to 99.6%. In a recent study Li et al. [49], used an autotrophic sulfur-limestone denitrification biofilter for municipal wastewater treatment in Changge, China. The biofilter presented removal efficiencies of total nitrogen (TN) and nitrate as nitrogen (NO_3^-–N) as high as 81.1 and 85.3%, respectively. Meanwhile, in Latin America, as in the rest of the world, several studies have been conducted regarding NbS, which will be discussed below.

NbS Use in Latin America

Figure 10.1 shows the most studied NbS in Latin America and their respective percentages in the selected countries. The results coming from the bibliometric analyses carried out as described in the materials and methods section. The countries with the largest number of studies on NbS are Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico, and Peru. Among the most studied NbS are biofilters, buffer strips, CWs, green roofs, green walls, stabilization ponds, and street trees. The country with the highest number of studies on NbS was Brazil, with a total of 319, followed by Mexico with 151 and Chile with 83 publications. Additionally, the technologies with the highest number of studies in Latin America were CW (38%), biofilters (23%), and stabilization ponds (16%). Furthermore, Fig. 10.1 shows the relationship between each NbS and the SDGs. In this regard, the SDG 6 "Ensure access and sustainable management of water and sanitation for all" was related to CW, biofilters, buffer strips, and stabilization ponds due to the ability of these technologies to treat wastewater by improving its quality [50]. In the case of SDG 9 " Build resilient infrastructure, promote sustainable industrialization and foster innovation", it was directly related to green roofs and green walls, since they promote innovation and enable sustainable and environmentally friendly infrastructure [51]. Similar to the case of SDG 9, the SDG 11 "Make cities inclusive, safe, resilient and sustainable" included green roofs, green walls, and street trees, since they have the ability to generate a pleasant and sustainable environment [52]. Regarding the SDG 13 "Take urgent action to combat climate change and its impacts" it was related to all the NbS, as they all aim to address climate change. Finally, the SDG 15 "Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss" was associated with CW, biofilters, buffer strips, and stabilization ponds, as these NbS are intended to prevent pollutants from different wastewaters from damaging the oceans and marine ecosystems [52].

Conversely, Fig. 10.2 shows the temporal evolution of NbS in Latin America. Figure 10.2a, shows the number of studies conducted on the different NbS during

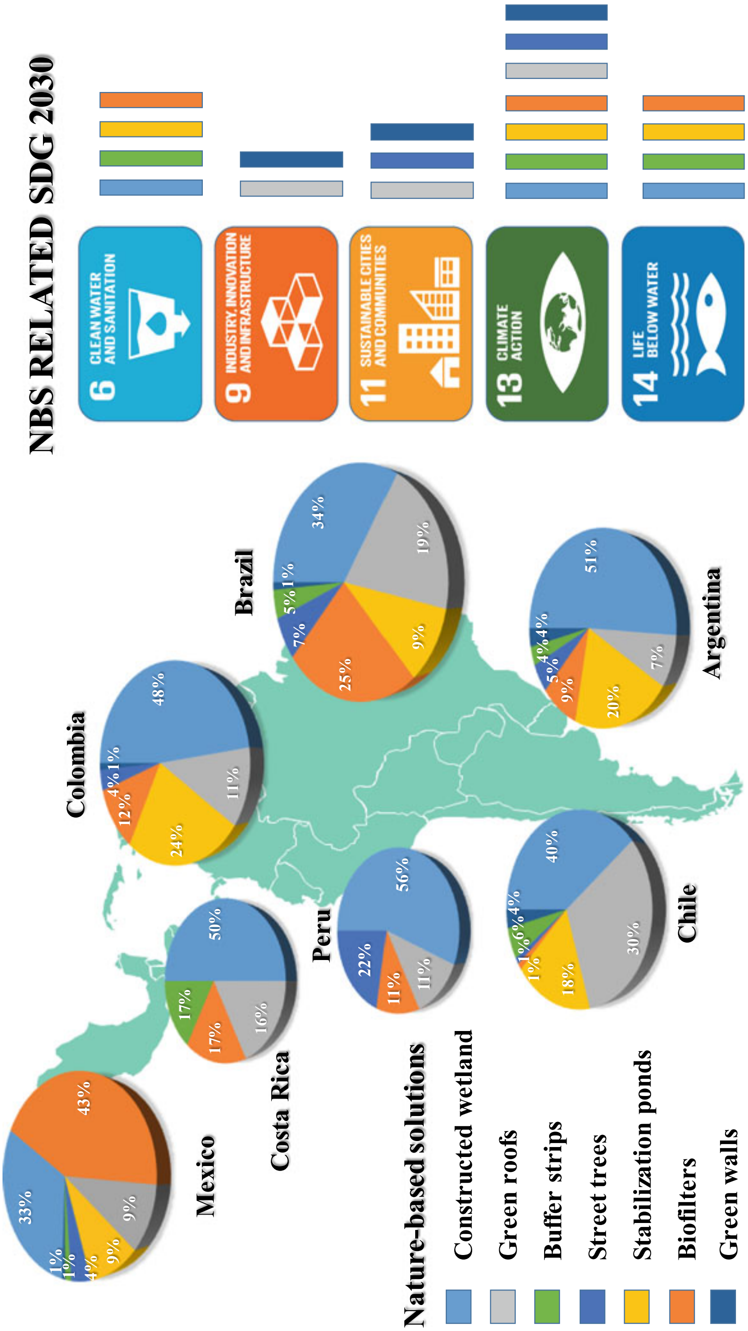

Fig. 10.1 Abundance of the most widely used of NbS in Latin America

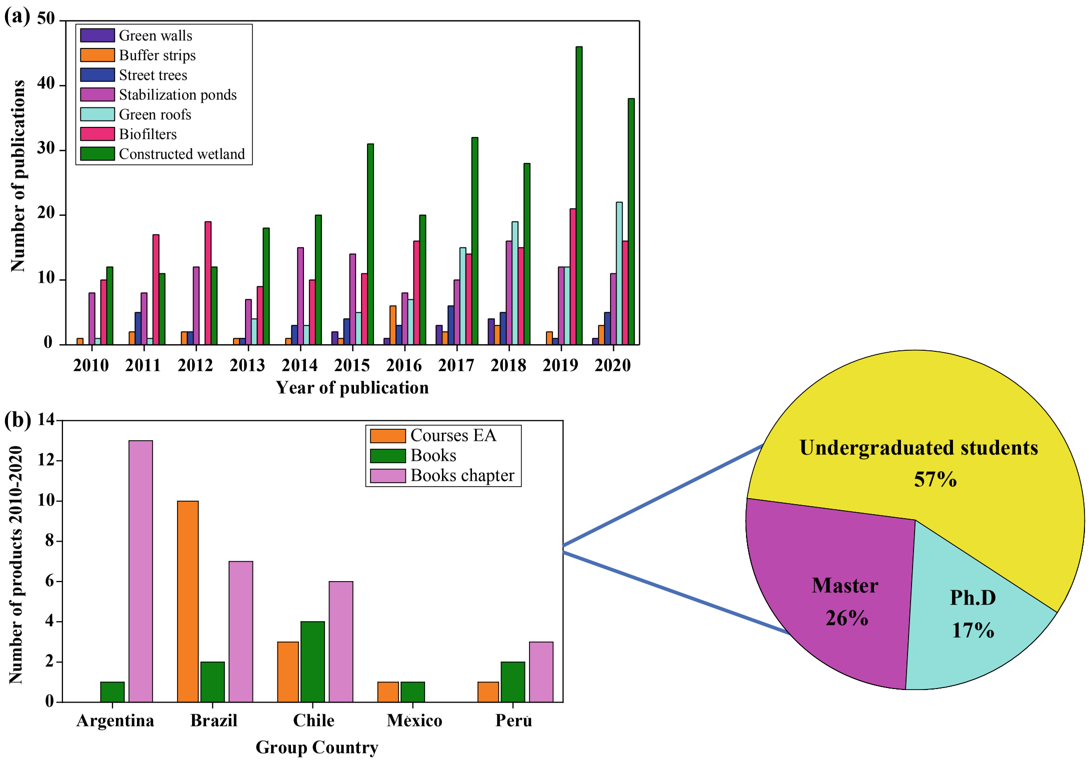

Fig. 10.2 Temporal evolution of NbS studied in Latin America: (**a**) the number of publications on the different NbS during the period 2010–2020; (**b**) the number of courses offer and book chapters and books published in different Latin American countries

the period 2010–2020. In Latin America, there were 706 studies about NbS, with Brazil (319), Mexico (151), and Chile (83) being the leading countries in this type of study. An increase of up to 65% in the number of NbS-related studies can be observed in the period 2010–2020, from only 32 published studies in 2010 up to 92 during 2020. The NbS with the highest number of studies per year were CW (38%), followed by biofilters (23%), stabilization ponds (16%), and green roofs (13%). Additionally, Fig. 10.2b shows the number of courses offer and book chapters and books published in different Latin American countries. For this study, research groups that are part of the HUPAMAN were directly reached. A total of 15 NbS courses were taught during the period included in this study, with Brazil offering the largest number, with 10 courses, followed by Chile with 3 courses. Among these courses, we can find Brazil: "Wastewater treatment", "Soil pollution control", "Disposal of wastewater in soil". Chile: "Summer courses on constructed wetlands". Peru: "Introduction to Nature-based Solutions". Mexico: "Bioremediation". In contrast, it was uncovered that some of the researchers also publish their results in book chapters. Moreover, there were 29 book chapters between 2010–2020, with Argentina being the country with the highest number of chapters, with a total of 13, followed by Brazil with 7. Some of book chapters are: "Processes of transformation and removal of metals in constructed wetlands for the treatment of effluents from metallurgical plants"—Argentina [53]; "Adaptação de parâmetros de projetos para lagoas de estabilização aplicáveis às condições climáticas da bacia hidrógrafica do Rio do Peixe"—Brazil [54]; "Strategies of the constructed wetlands operation under the perspective of the global change scenario"—Chile [55]; "Water sensitive urban design for metropolitan Lima, Peru-wastewater treatment park: the children's park"—Peru [56].

It was also possible to attest the effort to publish knowledge in open reference books that contribute to environmental education in NbS. During the period of study (2010–2020) a total of 10 books were tallied with Chile having the largest number with 4 books, followed by Brazil and Peru, with 2 books each. Among the books published we can find: "Constructed Wetlands: Design and Operation" [25], "Vegetable fibers and their applications: Innovation in their generation from water purification"—Chile [57]; "Constructed Wetlands for wastewater treatment"—Peru [58]; "Wetlands construídos aplicados no tratamento de esgoto sanitário: recomendações para implantação e boas práticas de operação e manutenção"—Brazil [59].

Case Studies of NbS Application in Latin America

As shown Fig. 10.1, within the most studied NbS were CW, Biofilter and Green Roofs. Table 10.1 shows a short summary of the 3 NbS selected: CW, Biofilter and Green Roofs. In regards to CW, a study conducted by Plaza de los Reyes et al. [60] in Chile, evaluated the performance of TN in a CW used as post-treatment of anaerobically treated swine wastewater, presenting removal efficiencies of 54.8–71.7%. Moreover, Leiva et al. [24] examine NH_4^+–N removal efficiencies in a vertical subsurface flow CW planted with *Agapanthus africanus*, presenting values higher

Table 10.1 Study cases of NbS used in Latin America

		Dimensions (m)						
NbS	Country	Length	Width	Height	Surface area (m^2)	Removal Efficiency	NBS positive impacts	References
Constructed wetland	Brazil	0.43	0.63	0.45	0.27	TN: 30–78%, TP: 11–47%	Municipal wastewater treatment	[61]
	Brazil	0.6	0.40	0.32	0.24	EE2: 9.0–95.6%, BPA: 29.5–91.2% and LNG: 39.1–100%	Endocrine disruptors removals in municipal wastewater	[63]
	Chile	2.9	1.45	0.57	4.21	BOD:53–67%, TSS: 85–93%	Municipal wastewater treatment	[66]
	Chile	1.9	0.3	0.5	0.57	As: (>99%)	As removal from municipal wastewater	[70]
	Argentina	0.6	0.55	0.55	0.33	Sil: 97%, Mp: 97%	Disposal of pharmaceutical and personal care products	[69]
Biofilter	Mexico	–	0.1	0.55	–	Mt: 94%, Cp: 81% and COD: 91%	Disposal of pharmaceuticals in municipal wastewater	[18]
	Chile	–	–	0.55	–	COD: 35–74% and N–NH_4^+: 9.6–57%	Municipal wastewater treatment	[71]
	Colombia	–	0.85	–	–	TSS: 31% and NH_4^+–N: 9.5%	Aquaculture water reuse	[72]
	Ecuador	–	0.32	0.32	–	BOD: 80–88%	Municipal wastewater treatment	[16]

(continued)

Table 10.1 (continued)

		Dimensions (m)						
NbS	Country	Length	Width	Height	Surface area (m^2)	Removal Efficiency	NBS positive impacts	References
	Costa Rica	–	0.19	0.8	–	Bromacil: 50–80%	Bromacil degradation	[73]
Green roof	Colombia	1.22	1.22	1.08	1.49	Temperature reduction: 13–18%	Passive climate control	[74]
	Brazil	–	–	–	1.00	Water retention: 78% and temperature reduction: 7–12°C	Rainwater retention and thermal attenuation	[75]
	Mexico	–	–	–	–	391 kgCO_2 eq/year	Reduction of GHG emissions	[76]
	Mexico	–	–	–	32	Uptake of 9 PAH	Uptake of PAH	[77]
	Argentina	6.8	1.8	–	12	Runoff retention: 30–100%	Reduction of surface runoff	[78]

Note As: arsenic, BOD: biological oxygen demand, BPA: bisphenol A, COD: chemical oxygen demand, Cp: ciprofloxacin, EE2: endocrinologists ethinyl estradiol, GHG: greenhouse gases, LNG: progestin Levonorgestrel, Mp: methylparaben, Mt: metformin, PAH: polycyclic aromatic hydrocarbons, Sil: sildenafil than 50%. In Brazil, Rigotti et al. [61] conducted a study on CWs that used two different macrophytes (*Typha domingensis* and *Schoenoplectus californicus*) and reported TN removal efficiencies of 30–78%.

Regarding organic matter removal efficiencies, several studies in Latin America have reported efficiencies ranging from 58–87% and 53–89% for COD and biological oxygen demand (BOD_5), respectively [21, 62–68]. In addition, CW have been studied for the elimination of endocrine disruptors and personal care products. In Brazil, Campos et al. [63], reported removal efficiencies of up to 91.2% for bisphenol A (BPA), while in Argentina, Delgado et al. [69] reported removal efficiencies of up to 97% de methylparaben (Mp).

When considering biofilters, these have been studied for municipal wastewater treatment, showing removal efficiencies of 35–80% for COD and up to 97% for TSS [16, 17, 71, 79]. Additionally, they have been studied with the objective of removing odors from municipal wastewater, that is the case in the study conducted by Allievi et al. [80] who reported a reduction in odors of up to 97%. In Mexico, García-Sánchez et al. [18] investigated a biofilter to remove pharmaceuticals products (Metformin and Ciprofloxacin) showing removal efficiencies of 94 and 81%, respectively.

In the case of green roofs, they have been researched with several different purposes. In Chile, Machado et al. [81] examined the capacity of a green roof to store rainwater, presenting a storage capacity of 3.26–291.08 m^3 of usable water. In a recent study in Colombia Osuna-Motta et al. [74] investigated the thermal performance of a green roof (passive cooling capacity). They reported a reduction in indoor temperature of up to 13–18%. These case studies provide empirical evidence that the implementation of NbS in Latin America contributes to sustainability and they help improve people's quality of life.

Perspectives of NbS Application in Environmental Education

Faced with the current climate change scenario, it is essential that the various professionals can evolve towards learning about topics that consider the knowledge of the environment and that the new technologies that are implemented take into account climate change adaptation and mitigation towards territories resilience. Thus, it is essential that they receive training in environmental education in order to plan and build solutions focused on NbS, with the aim of avoiding the collapse of infrastructures that are not adequately designed/operated to faced extreme changes in temperature, water flow, among others [82–84]. Considering the previously mentioned, Vera-Puerto et al. [83] conducted a study with the aim of determining the different competencies to be included in the various civil engineering programs in Chile to develop NbS-based water infrastructure in the urban context. In their study twenty-one competencies were determined, including those related to water quality, treatment process design to improve water quality, legislation, circular economy, equipment, climate and construction materials.

According to the information provided by investigation groups from HUPANAM, several different engineering programs are introducing the integration, dissemination, and implementation of the NbS at the various formal levels of their curricula. The training of these students is scientific. At the same time, graduate students from Latin American universities with competencies in NbS are being trained, in order to generate research and publications with the knowledge derived from the execution of graduate theses that are being conducted in different Latin American countries. For example, in investigation group from Peru are being included CW training in the curricula of undergraduate courses as green technologies for adaptation to climate change, and extreme scenarios, among others. These efforts to implement environmental education based on NbS are very important and should continue to be promoted in Latin America in order to contribute to sustainability and resilience in the face of climate change.

Despite the increase in the number of publications, book chapters and books, and the generation of curricula that integrate the NbS in Latin American universities at the undergraduate and postgraduate level, the integration between NbS and environmental education is far from being a reality in Latin America. According to Briggs et al. [11], the huge gap in environmental education in Latin America is the knowledge access related to the cultural context. This study evidence the limited documentation, coverage and accessibility of information about environmental education initiatives in Latin America. This result reveals that, Latin American investigation groups and universities must make an important effort to generate knowledge related to NbS, with a real impact on environmental education. It is necessary not only that undergraduate and graduate university education include environmental education as a curricula base, but also school education and community education.

Conclusions

From this study, it is possible to observe that there are several countries in Latin America that are very active in the generation of knowledge on NbS through research and publication of their findings in WoS-type publications. During the period 2010–2020, the number of publicationsincreased up to 65% from only 32 published studied in 2010 to 92 during 2020. Likewise, the knowledge generated in the region is being disseminated in books and book chapters with a number of 10 and 29, respectively. According to the HUPANAM information, in Latin American countries exist a clear motivation for the study and implementation of the NbS in universities curricula at undergraduate and postgraduate level. These initiatives have the purpose of advancing in environmental education, sustainability and improvement in the population's life quality due to the various benefits that the NbS provide. Furthermore, the university institutions play an important role in conjunction with postgraduate studies granting a greater NbS divulgation at the various levels of education. Taking the above into account, the challenge arises of expanding the knowledge and dissemination of these technologies and environmental education to scholar education level.

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Chapter 11
Lessons Learned from Introducing Aquaponics to Higher Education Curricula

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Abstract Aquaponics is an innovative and sustainable food production technology which has the potential to make a significant contribution to twenty-first century food systems, especially if there is an adequately trained workforce. In this chapter we review the efforts of an international consortium to develop a curriculum for teaching the basics of aquaponics to final year undergraduates and Masters students. As a nature-based solution which addresses a number of socio-environmental challenges, including food and water security, water pollution, human health, and climate change, aquaponics combines aquaculture and horticulture in an ecologically balanced closed-loop system. Teaching aquaponics promotes ecological literacy among students, thereby enabling future professionals of various careers whose

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activities are affected by—and have consequences for—environmental issues, and provides a pathway for introducing the concepts of sustainable development and the circular economy to higher education curricula.

Keywords Aquaculture · Hydroponics · Blended learning · Moodle · Sustainable development · Circular economy

Introduction

Combining two technologies—recirculating aquaculture and hydroponics—in a closed-loop system, aquaponics offers an opportunity to produce food in an environmentally sustainable way, using low levels of resource input [1, 2]. Unlike field-based food production systems, which rely on the availability of non-renewable resources such as phosphorus and potassium, in aquaponic systems the plants grow in water and the nutrients are provided by fish feed and fish waste [3]. A soil-less food production technology such as aquaponics therefore neither contributes to nor exacerbates problems such as over-fishing in the sea, water scarcity and soil/water degradation caused by intensive farming, and the use of antibiotics in aquaculture and pesticides and herbicides in field production. Controlled-environment agricultural technologies, including aquaponics, are likely to become more important in the future due to climate change, which will make conventional field-based farming more vulnerable, while the phenomenon of 'food miles' [4] plays to the strengths of local production of food, especially within cities, by shortening food supply chains and improving the security and resilience of food systems [5].

This chapter discusses the lessons learned during the Aqu@teach project, an Erasmus+ Strategic partnership for Higher Education (2017–2020) between the University of Greenwich (UK), the Zurich University of Applied Sciences (CH), the Technical University of Madrid (ES), the University of Ljubljana and the Biotechnical Center Naklo (SI). To develop aquaponics as a commercially viable food production technology, it is of the utmost importance to create an appropriately trained workforce. The Aqu@teach project aimed to address that need by developing the first aquaponics curriculum specifically for higher education students. Aquaponic food production requires a broad spectrum of knowledge—aquaculture, horticulture, chemistry, biology, food safety, and engineering—in order to understand and manage the processes involved. The aquaponics curriculum was therefore designed to equip students with expert knowledge and skills, as well as digital, entrepreneurial, and transferable skills that will give them a competitive advantage in the labour market. Given the multidisciplinary nature of aquaponics, the curriculum can be taught as an optional module in a wide variety of degree courses, including agriculture, agronomy, horticulture, aquaculture, ecological engineering and landscape architecture. Indeed, catering for the variety of backgrounds of the potential students was one of the greatest challenges that the consortium faced when developing the curriculum [6].

Hosted by the open source Moodle virtual learning environment, Aqu@teach was designed to be taught either using blended learning—combining digital media and the internet with classroom formats that require the physical co-presence of the teacher and students—or as an e-learning course. All of the Aqu@teach resources—the e-learning modules, textbooks [7, 8], module guides for students, curriculum guides for teachers, best practice guide for teaching aquaponics, and toolbox of innovative didactic practices—are open access and have been released with Creative Commons NonCommercial-ShareAlike licenses (https://aquateach.wordpress.com), which means that educators can alter the contents as they see fit. This flexibility was designed to ensure that the curriculum can be adopted as widely as possible.

Aquaponics as a Nature-Based Solution (NBS)

Aquaponics combines two food production technologies—hydroponics and recirculating aquaculture—that emerged in the second half of the twentieth century in response to the need to use locally limited water resources more productively. The primary goal of aquaponics is to use the nutrients contained in fish feed and fish faeces in order to grow crops [1, 9, 10], and the integration of both systems removes some of the unsustainable factors associated with running aquaculture and hydroponic systems independently [11]. However, the principle can also be applied to other combinations of technologies—such as pond aquaculture with hydroponics, or tank based aquaculture with field cultivation—and settings (permanently or on-demand decoupled systems) [12].

As a NBS, aquaponics can positively contribute to a variety of environmental and societal concerns (Fig. 11.1). Through nutrient, resource and waste recycling, aquaponics can address problems related to planetary boundaries—the environmental limits within which humanity can safely operate with regard to scarce resources, in particular biogeochemical flows, freshwater use and land-system change [13]. Nitrogen (N) and phosphorus (P) are essential elements for plant growth, yet their biogeochemical flows have been radically changed as a result of agricultural and industrial practices. The major perturbation of both cycles arises from the application of fertilizers. Anthropogenic activities now convert more atmospheric N into reactive forms than all of the Earth's terrestrial processes combined. Rather than being taken up by crops, much of this reactive N is emitted into the atmosphere, and when it is rained out it pollutes waterways and coastal zones, or accumulates in the terrestrial biosphere. Similarly, a relatively small proportion of the P fertilizers applied to crops is taken up by the plants; much of it ends up in aquatic systems which then become oxygen starved as bacteria consume the blooms of algae that grow in response to the high nutrient supply [14]. Each year millions of tons of fossil P are mined and processed, and demand for P fertilizers continues to grow exponentially, yet rock phosphate reserves are both depleting and non-renewable, while the potential to recover and recycle waste P (in sewage sludge, manure and food waste)

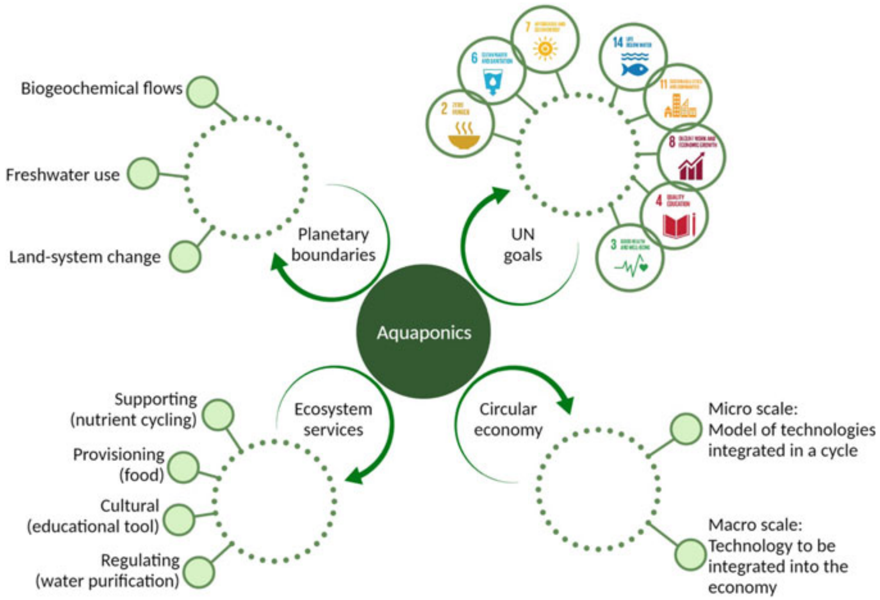

Fig. 11.1 Aquaponics as a nature-based solution

remains untapped or inefficient [15]. In aquaponic systems microbes convert the N and P present in fish effluent and in uneaten feed into bioavailable forms to the plants.

Water scarcity is another important factor constraining food production. The freshwater cycle is strongly affected by climate change, yet human pressure is now the dominant driving force determining the functioning and distribution of global freshwater systems. By 2050 about half a billion people are likely to be subject to water stress [14], which will require more efficient use of water in both agriculture and aquaculture. Recirculation of water in aquaponic systems can achieve water re-use efficiency rates of 95–99% [16].

Land-use change—from forests, grasslands, wetlands and other vegetation types to agricultural land— has impacts on water flows and on biogeochemical cycling. While each incidence of land cover change occurs on a local scale, the aggregated impacts can have consequences for Earth system processes on a global scale [14]. As a soil-less cultivation system, aquaponics reduces the land footprint needed for food production. Aquaponic farms can be situated on non-agricultural land in peri-urban or urban areas closer to markets, thus reducing the carbon footprint associated with the transportation of products from rural farms.

A proposed approach for the United Nations Sustainable Development Goals (SDGs) argues that the stable functioning of the Earth system is a prerequisite for thriving societies around the world [17]. This approach implies that the planetary boundary framework, or something similar, will need to be implemented alongside the achievement of targets aimed at more immediate human needs [14]. The 17 SDGs comprise a total of 169 targets which have been established to provide a basis for major advances towards achieving the overall goals through concrete objectives, such as doubling agricultural productivity, or improving water quality. Three of the SDGs are intrinsically linked: food (SDG 2), water (SDG 6) and energy (SDG 7). The interconnectedness between these goals, often referred to as the 'water-energy-food nexus', implies the potential for synergies but also the risk of trade-offs. Synergies are the positive effects of a target achievement that facilitate the achievement of another target, while trade-offs are created when one target intensively uses resources necessary for the achievement of another target, or when environmental degradation caused by the achievement of one target limits the chances of achieving another. For example, Target 2.3 'Double the productivity and incomes of small-scale food producers' could result in expanded use of fertilizers and agrochemicals, which could then potentially compromise Target 6.3 'Improve water quality, wastewater treatment and safe reuse'. An assessment of synergies and trade-offs between the goals relating to the water-energy-food nexus confirmed the general belief that SDG 6 (water) has the highest number of potential synergies with other goals. Thus, achieving water targets will make it continuously easier to achieve more goals and targets, including those outside the water-energy-food nexus [18].

Nutrient recycling in aquaponic food production, and the use of integrated pest management (IPM)—an ecosystem-based strategy that focuses on the long-term prevention of pests through a combination of biological control, habitat manipulation, modification of cultural practices and the use of resistant plant varieties—instead of pesticides, removes the potential conflict between targets 2.3 and 6.3, while water recycling contributes to Target 6.4 'Increase water-use efficiency and ensure freshwater supplies'. Technological advances in the design of aquaponic systems are making them increasingly 'energy smart', by moving away from fossil fuels to using electricity generated from renewable sources, thereby contributing to Target 7.2 'Increase global percentage of renewable energy'. Even in temperate latitudes, new designs allow the energy involved in heating and cooling the fish tanks and greenhouses to be fully integrated, such that they do not require inputs beyond solar arrays or the electricity/heat generated from bacterial biogas production using the fish sludge [19, 20]. Aquaponic technology can be viewed as a primary example of 'ecological intensification' in food production—the environmentally friendly replacement of anthropogenic inputs and/or enhancement of crop productivity by including regulating and supporting ecosystem services [21]—since its founding principles are based on the management of service-providing organisms towards quantifiable and direct contributions to food production [22].

Aquaponics as an Educational Tool

In addition to supporting ecosystem services (nutrient cycling), regulating services (water purification) and provisioning services (food), aquaponics provides cultural services as an educational tool. It promotes scientific literacy and provides an innovative tool for teaching environmental sciences at all levels of education. As a model for agronomic and aquatic systems, an aquaponic system encourages curiosity, critical thinking and creativity, while affording opportunities for experiential learning. Over the past three decades there have been various initiatives using classroom-scale aquaponic systems for hands-on teaching and learning of science, technology, engineering and maths (STEM) and food-related subjects in schools in North America [23–35], Europe [36, 37] and Asia [38, 39].

Higher education curricula in particular need to be adapted to meet the expectations of the new millennium, and aquaponics can be used to introduce topics such as long-term food security, sustainable food production, rural development and zero hunger [37]. Introducing aquaponics to higher education curricula can also provide a pathway for embedding teaching of the SDGs. As significant influencers and agents of change, universities need to play a more prominent role in the change process catalysed by SDGs. Implementing SDGs requires a wide range of social, economic and environmental challenges to be addressed, involving complex interlinkages, uncertainty and conflicts of values. Providing learners with the skills to think through complexity, learn through dialogue and communication, engage in deep reflection, develop worldviews, and assess when activities support or detract from achieving the SDGs will help to accelerate their implementation [40]. Target 4.7 of SDG 4 Quality Education is 'Education for sustainable development and global citizenship', of which the indicator is the 'extent to which (i) global citizenship education and (ii) education for sustainable development … are mainstreamed at all levels in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment'. Sustainable development touches numerous disciplines, including environment, biology, agronomy, engineering, architecture and economics. Given the breadth and interconnectedness of the sustainable development agenda, the SDGs cannot be pursued in isolated disciplines. Interdisciplinary subjects such as aquaponics can increase the ability to understand the challenges that the world currently faces and, as noted above, is particularly appropriate for examining the water-energy-food nexus (SGD6, SDG7 and SGD2). Integrating disciplines facilitates problem-solving as it promotes better understanding of each part that comprises the problem, and fosters solutions that blend concepts from different disciplines [41].

Teaching aquaponics also affords an opportunity to introduce students to the concept of the circular economy, since it embodies the principles of 'a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops' [42]. The concept of the circular economy has gained importance on the agendas of policymakers, as evidenced by the European Union (EU) Circular Economy Action Plan which highlights its essential role in the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy [43]. Higher education plays a vital role in the global transition to a circular economy, not just from the point of view of teaching and research, but also in terms of procurement decisions. As a model of production and consumption, the circular economy is relevant to many disciplines, and front runner attempts to incorporate it in university curricula include design [44], energy policy [45], business [46] and environmental sciences [47]. Water resource recovery is central to the circular economy framework. It underlies the transition of environmental engineering from pollution prevention to responsible innovation for sustainable systems engineering [48]. In order to speed this transition, resource recovery and circularity need to be integrated into new higher education curricula [49].

Aquaponic systems are circular by design. While an aquaponic system may be categorized as a micro-level economic activity in the circular economy, there may be further opportunities to develop synergetic meso-level activities, by investigating the system inputs and outputs along the value chains of the business in order to provide more opportunities to close the loops. For example, local food waste could be used as substrate for rearing and feeding insects to make a sustainable alternative to off-the-shelf fish feed. In addition, by operating systems in buildings and on rooftops, a synergy can be created between a farm and its host building by coupling the flows of the production process—heat, water, and CO_2—with those of the building, in order to close the waste, resource, and energy loops.

Teaching aquaponics promotes ecological literacy among students, thereby enabling future professionals of various careers whose activities are affected by, and have consequences for, actual environmental issues. The literature on ecological literacy emphasizes the role of scientific knowledge and ecological thinking in identifying cause-effect relationships in socio-environmental systems, in order to allow more enlightened decision-making in real-world environmental issues that professionals in careers as diverse as engineering, public health, architecture, social sciences, or management will address. Ecological literacy therefore enables conscious and participant citizens to make informed decisions or to take action. If a broad gamut of professionals is enabled, the consequences should be felt not only in their own occupations, but also in wider communication, opinion-forming, and decision-making spheres [50].

At universities and colleges, the context for course content development is specific to each institution's internal and external dynamics. In the United States aquaponics is taught as part of a wide range of science curricula—primarily aquaculture, but also environmental science, food systems, biology, chemistry, horticulture, agriculture, engineering and marine science. Interest in aquaponics among colleges and universities parallels renewed interest in agriculture programmes and teaching farms at higher education institutions [26]. As part of the Aqu@teach project we conducted a survey of higher education institutions across Europe in order to gauge the extent to which aquaponics is currently embedded in the curricula of aquaculture, horticulture, agronomy, environmental engineering and landscape architecture degrees (Table 11.1). Of the respondents that teach aquaculture, only two-thirds include some teaching of aquaponics. There is also variation within the same country, with some universities including aquaponics in their aquaculture curriculum, and others not. Only a small number of respondents teach aquaponics as part of an agronomy or environmental engineering degree, and none of the respondents from horticulture or landscape architecture departments teach aquaponics. This is perhaps not surprising. The main challenge in teaching aquaponics at higher education level is the interdisciplinary nature of the subject, requiring good knowledge of both aquaculture and horti-

Table 11.1 Results of the survey of higher education institutions in Europe (n = 42)

	Teach some aquaponics		Do not teach any aquaponics	
Curriculum	Country	No		No
Aquaculture	Belgium Estonia Finland Germany Greece Hungary Ireland Italy Serbia Spain Switzerland Turkey United Kingdom	1 2 1 2 1 2 2 2 1 1 1 1 3	Croatia Denmark Estonia Italy Macedonia Serbia Turkey United Kingdom	1 1 1 1 1 1 1 2
Horticulture			Slovenia United Kingdom	1 1
Agronomy	Germany Switzerland United Kingdom	1 1 1	Romania	1
Environmental engineering	Portugal Spain	1 1	Italy	1
Landscape architecture			Croatia Ireland Poland United Kingdom	1 1 1 1

culture, as well as aspects of chemistry, biology, food safety, and engineering, and educators may feel ill-equipped to deliver such content. The Aqu@teach curriculum was therefore developed in order to facilitate this.

Aqu@teach: The Aquaponics Curriculum

The aquaponics curriculum is divided into 15 modules: (1) Aquaponic technology, (2) Aquaculture, (3) Fish anatomy, health and welfare, (4) Fish feeding and growth, (5) Nutrient water balance, (6) Hydroponics, (7) Plant varieties, (8) Integrated pest management, (9) Monitoring of parameters, (10) Food safety, (11) Scientific research methods, (12) Design and build, (13) Urban agriculture, (14) Vertical aquaponics, and (15) Social aspects of aquaponics. The student workload is 150 h, corresponding to 5 ECTS.

Curriculum Design

The aquaponics curriculum was developed in accordance with the recommendations of the Standards and Guidelines for Quality Assurance in the European Higher Education Area [51] and Considerations for Quality Assurance of E-learning Provision issued by the European Association for Quality Assurance in Higher Education [52]. According to these recommendations, higher education e-learning programmes should be delivered in a way that encourages students to take an active role in creating the learning process, and this should be reflected in the way that they are assessed. Student-centred learning, teaching and assessment should involve the use of flexible learning paths, different modes of delivery and a variety of pedagogical methods, and students should be given a sense of autonomy. Since digitising content alone does not lead automatically to a successful educational setting, institutions should design their curriculum in such a way that it stimulates and engages students in the learning process, and reflects best practices and research in teaching and learning. In order to overcome the lack of direct face-to-face interaction, students may need encouragement to engage online with each other. This can be facilitated by the use of online discussion groups for student-to-student contact, and online spaces for communication between teachers and students.

The aquaponics curriculum adopts the student-centred pedagogy of problem-based learning (PBL) in which students learn about a subject through the experience of solving an open-ended problem found in trigger material. The PBL process does not focus on problem solving with a defined solution, but it allows for the development of other desirable skills and attributes. This includes knowledge acquisition, enhanced group collaboration, and communication. The PBL tutorial process involves working in small groups of learners, and is focused on the student's reflection and reasoning to construct their own learning, by clarifying terms, defining problems, brainstorming, independent study, and synthesis. In short, it is identifying what they already know, what they need to know, and how and where to access new information that may lead to the resolution of a problem. The role of the tutor is to facilitate learning by supporting, guiding, and monitoring the learning process. PBL is being increasingly used in higher education and there is evidence that it has a positive effect on the students' motivation, on long-term retention of learned outcomes, and on students' higher cognitive skills [53].

The curriculum was co-designed with students, using comprehensive feedback on a pilot run in the spring of 2019. The process started off by exploring various innovative didactic tools that could be used for teaching aquaponics online, such as social bookmarking, image sharing, note sharing and interactive videos and, using this knowledge, the activities in Moodle were designed. Each of the modules involved a range of collaborative activities, some of which are inherent in Moodle, such as workshops, wikis, and discussion forums, while others involved external platforms, namely the Flickr image sharing service (flickr.com) and the Diigo social bookmarking website (diigo.com). Moodle has built in many activities that encourage students to use different ways to engage with the material in a course, and different ways to interact and express themselves. It offers ample opportunities for the three types of interaction that are required for effective learning—learner-content, learner-instructor, and learner-learner—and the six types of learning which, together, constitute a good learning design—acquisition, inquiry, production, practice, discussion and collaboration [54]. Moodle's design is driven by social constructivist pedagogy. Constructivists see learners as being active rather than passive, whereby they create knowledge through the process of constructing artefacts—text or other media—within a social environment, rather than being given knowledge through instruction. The student is therefore at the centre of the learning, with the instructor playing an advisory and facilitating role [55].

Part of the reason for including the Flickr and Diigo activities was the desire to create a community of learning involving the students and teachers from the five participating institutions, since the pilot run of the aquaponics curriculum was scheduled to take place before an entrepreneurial skills summer school in Slovenia. Social bookmarking platforms such as Diigo are useful tools for sharing online learning resources and, as an emerging educational technology, have been attracting educators' attention over recent years. Since the bookmarks are hosted in the cloud and are not linked to a specific computer, the information is accessible from any device with Internet access. These tools enable users to collaboratively underline, highlight, and annotate an electronic text, which raises the possibility of the collective discovery and construction of disciplinary knowledge by students in collaboration with each other and with the tutor [56–58]. Studies have shown that students perceive the use of social annotation tools to be an enjoyable activity [59, 60].

As with other social media technologies—social networking sites and social bookmarking platforms—image sharing sites such as Flickr can be used to build a virtual education community involving students from different institutions. Although information is primarily conveyed by the visuals, captions can be used to elaborate on the contents of an image or video, and instructors can use them to supply links to other online resources or to assign activities for students that include posting other related images or making comments. While Flickr could usefully be used by the teacher to create a course-specific image bank for the students, thereby driving the content and processes of learning, the real value of image sharing platforms as a tool for student-centred pedagogy lies in the fact that the students can co-construct the content and, in so doing, specify what knowledge is of worth in their learning.

The various activities in each module were intended to encourage a mixture of student dialogue and collaboration, autonomy, critical thinking, and creativity. The open source Learning Designer software (https://www.ucl.ac.uk/learning-designer/) was used, which helps teachers to design learning experiences as sequences of teaching and learning activities that will help students move towards their learning goals, and to achieve a balance between Laurillard's six types of learning [54]. Table 11.2 shows examples of Moodle activities mapped against the different categories of Bloom's revised Taxonomy of Educational Objectives, while Table 11.3 shows examples of some of the activities in Module 13 Urban Agriculture mapped against the six types of learning.

Table 11.2 Examples of Moodle activities mapped against the different categories of Bloom's revised taxonomy of educational objectives

Bloom's taxonomy	Moodle activity	Example
REMEMBER Recall facts and basic concepts (e.g. *define*, *list*)	Glossary	Look up any unfamiliar terms in the textbook chapter and add them to the glossary
UNDERSTAND Explain ideas or concepts (e.g. *describe*, *identify*)	Wiki	Create a Wiki on the five stages of an integrated pest management programme suitable for aquaponics
APPLY Use information in new situations (e.g. *solve*, *demonstrate*)	Workshop	Calculate fish feed and total ammonia nitrogen for a 250 L tank with a stocking density of 24.6 kg/m^3 and an average fish weight of 400 g
ANALYZE Draw connections among ideas (e.g. *differentiate*, *compare*)	Wiki	Produce a wiki on the five types of hydroponic substrate that are most widely available. How do different brands of the same substrate type differ in terms of their constituent elements and cost?
EVALUATE Justify a position (e.g. *argue*, *critique*)	Forum	Do fish feel pain?
CREATE Produce new or original work (e.g. *design*, *assemble*)	Workshop	In your aquaponic system you want to grow a polyculture of leafy greens, herbs and flowers as a commercial enterprise. The growing area is 300 m^2. Choose your species and varieties (cultivars) and, using Excel, create a crop schedule

Curriculum Evaluation

The aquaponics curriculum was pilot tested over a five month period as an instructor-led, cohort-based e-learning course at each of the five partner institutions, with students studying very different disciplines: landscape architecture (Greenwich), agricultural engineering (Madrid), natural resource sciences (Zurich), sanitary engineering (Ljubljana), and horticulture (Naklo). Five students from each institution were selected on the basis of their motivation and previous academic performance. The curriculum was evaluated based on comprehensive student feedback on each individual module and on the various teaching and learning methods used, and self-evaluation by the tutors. For each module, the students were asked to provide feedback on the level of content, the textbook chapter, the degree of knowledge gain, the teaching methods used, the balance of activities, the number of hours taken to complete it, and how it could be improved. Regarding the various teaching and learning methods used, the students were asked to evaluate which activities enhanced

Table 11.3 Examples of some of the activities in Module 13 Urban Agriculture mapped against the six types of learning

Learning type	Activity	Example
ACQUISITION Reading, listening, watching	YouTube videos	Watch the videos about two commercial urban agriculture start-ups: Localize and Gotham Greens. Make notes on the factors that motivated these entrepreneurs to start a business, and how they went about it
INQUIRY Researching	Internet search	Search the internet for urban agriculture enterprises operating in your city. What are the features of these, in terms of their business model (non-profit, for-profit, or non-profit/for-profit hybrid) and the products and/or services they provide?
DISCUSSION Asking questions	Forum	Discuss your findings with your fellow students in the Moodle Forum. Can you identify a gap in the market which you could potentially exploit?
PRODUCTION Producing something for teacher or peer evaluation	Assignment	Use the internet to help you find crops that have a high retail price in your country. You also need to identify your target customers – who is going to buy your produce? Define your USP (unique selling proposition) – what makes your product stand out from that of your competitors? Summarise your reasons for your choice of crop(s), your target customers, and your USP, and upload your work to Moodle for feedback from your tutor
COLLABORATION Shared student activities resulting in a shared output	Wiki	Search the internet for legislation that you need to be aware of in order to bring your indoor urban farm to fruition in your city. Summarise your findings in the Wiki
PRACTICE Performing a task	Quiz	10 question multiple choice quiz. The results will be recorded and will count towards your final grade

the learning process, and whether the time and effort needed to complete them was proportionate to the learning benefits.

Figures 11.2 and 11.3 summarize the feedback from the students on which of the various teaching and learning activities enhanced the learning process. The feedback on the Flickr and Diigo activities was overwhelmingly negative, since they involved using platforms external to the Moodle environment which required registering for

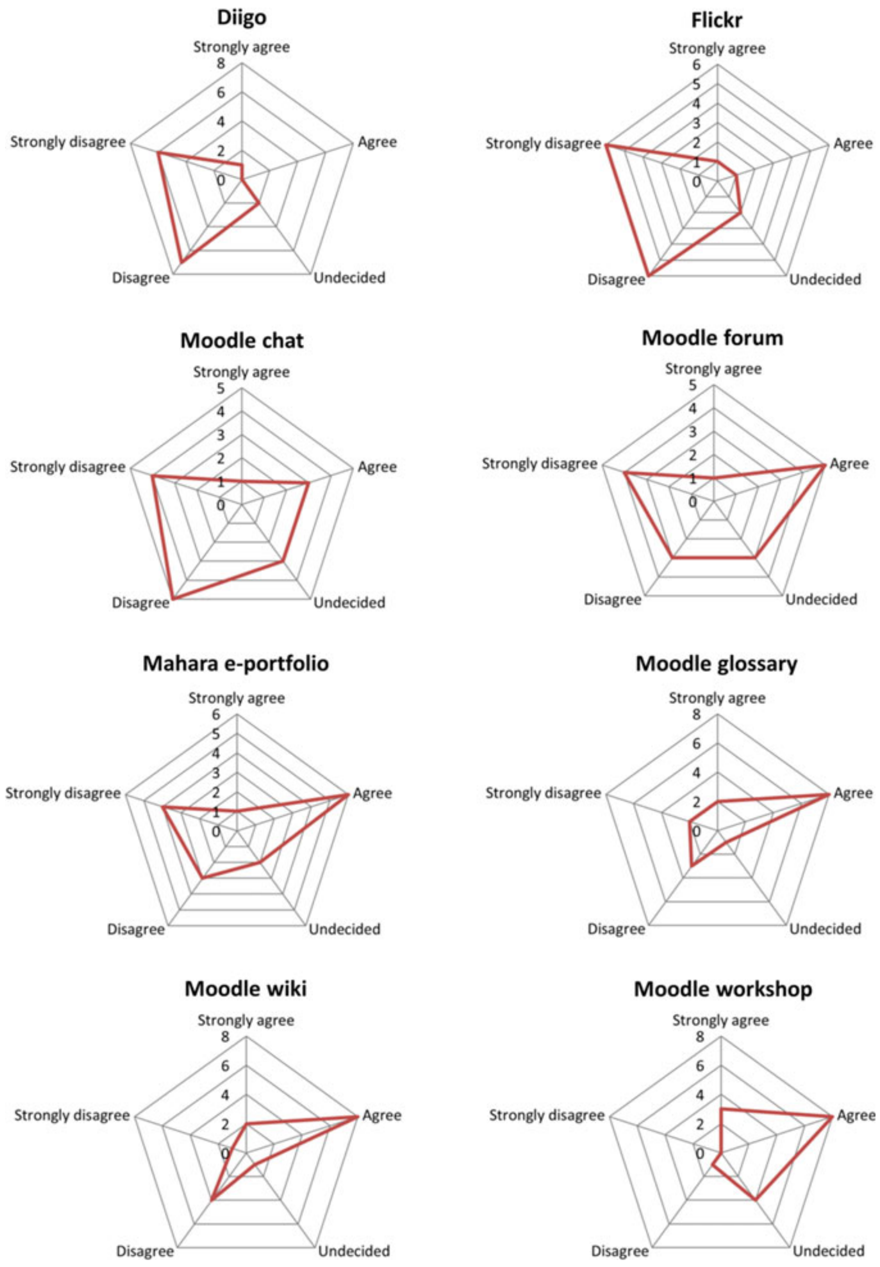

Fig. 11.2 Student Likert scale ranking of whether the activities enhanced the learning process

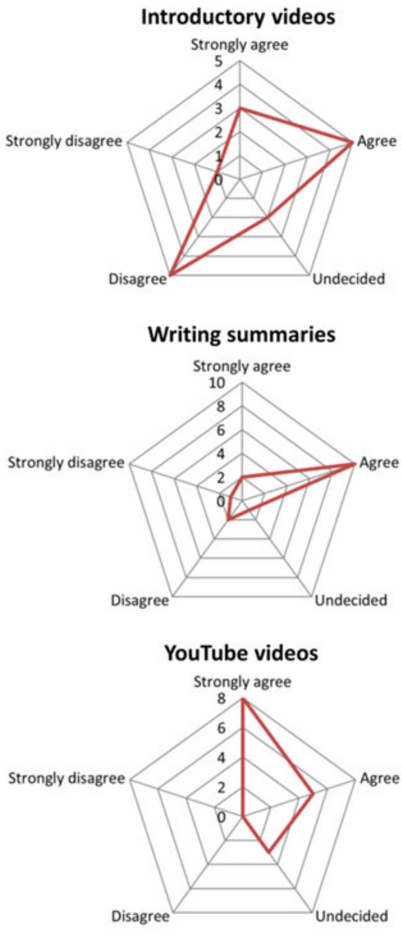

Fig. 11.3 Student Likert scale ranking of whether the activities enhanced the learning process

an account, and it took additional time to learn how to use them. Student perception of the various Moodle activities was mixed. Chat and, to a lesser extent, Forum were the least effective, from the students' point of view. The Chat activity allows course participants to have a real-time synchronous discussion, while the Forum activity enables students and teachers to engage in asynchronous discussion. In Aqu@teach the Forum is used to enable the students to critically evaluate the knowledge they have acquired from their reading, watching or searching activities. While in theory it gives participants more time to reflect, which provides more in-depth discussion, in practice students have a tendency to make a posting and then not return to the Forum, thus precluding the possibility of any real discussion taking place. Based on our experience, it would be more effective to schedule discussions as a synchronous online activity, with active engagement of the tutor in order to keep the momentum going and to prevent the discussion from straying off topic. In order to encourage more effective discussion, a teacher could also require that each student responds to a minimum number of postings made by others. Alternatively, if the curriculum is taught in a blended learning format, the discussions can take place face-to-face, since students tend to prefer this.

The Glossary, Wiki and Workshop activities were more favourably received by the students. The Glossary encourages students to create and maintain a communal alphabetical list of technical terms and their definitions, and is a useful way of familiarising students with new terminology, and a handy reference tool. When students are responsible for creating the definitions, they are more likely to remember the word and the correct definition. However, some students may not be motivated to add definitions, or may make errors in their entries. Linking Glossary activities to external motivators, such as assessments and quizzes, might be needed in order to encourage its use and therefore support active and independent learning. The input of the teacher through the editing function is vital to ensure that entries are of good quality, and feedback or a discussion around the entries is helpful for students to understand mistakes. It may also be a good idea to ask the students to include examples of uses of the new words in context.

The Wiki is a hypertext that is collaboratively produced and edited which provides a useful forum for sharing the results of a research activity. While it is easy to use, students may misunderstand that the document is meant to be both collaboratively produced and edited. For a Wiki to work well as a learning space, one which is characterized by genuinely collaborative writing and collective meaning-making, it is necessary to nurture among students a sense in which it is acceptable to be critical—to edit, amend and challenge each other via the direct manipulation of each other's text. For the teacher in the Wiki, the key challenge is to nurture in students this sense that to do so is not a breach of trust but an act of responsibility and mutuality.

The Moodle activity most favoured by the students was Workshop, which is a powerful peer assessment activity. Students submit their own work, and then receive one or more submissions from a fellow student which they must assess according to a predetermined list of criteria. Workshop exposes students to solutions, strategies and points of view that they would not otherwise see, and it develops a better understanding of a student's own subjectivity and judgement. Students can also provide more effective feedback than tutors, by providing explanations to their peers in terms they understand best. However, some students can be uncomfortable with the idea of evaluating the work of their peers, and may also feel unconfident about the strength of their own work, which will make them question their ability to assess the same assignment produced by someone else. This could be alleviated by the teacher providing guidance in the form of example submissions for them to try out beforehand, and by sharing some good (or less good) examples at the end of the activity.

Mahara e-portfolio is an open source Moodle plug-in which enables students to create a digital collection of the results of their learning activities. It enables different 'artefacts' (text, images, videos, etc.) to be placed together on a page, and for different pages to then be grouped together to form a thematic collection. For example, the pages relating to the practical tasks in the various modules could all be grouped together, and thus serve as a useful reference source. The e-portfolios were used for summative assessment of the students, alongside the final quiz in each module. The feedback from the students on their experience with the e-portfolio was mixed, and some students did not engage with it as fully as they might have. Unless a student personally invests in the tool, it is unlikely that it will be utilised to its full potential. The challenge for instructors is therefore to adopt strategies which motivate the students to readily engage in the e-portfolio process by highlighting its value and usefulness, both for the task at hand and in the future, since employers are increasingly aware of and willing to accept e-portfolios to evaluate job applicants. Teachers should share examples of best practice with their students, so that they are clear what is expected of them, and should recommend that the students start planning the layout of their e-portfolio at the beginning of the course, rather than at the end, so as to prevent them from trying to create order out of chaos.

Feedback on whether the time and effort needed to complete the various activities was proportionate to the learning benefits broadly mirrored the feedback on whether the various activities enhanced the learning process, with one notable exception. The majority of the students felt that the amount of time spent doing internet search activities was disproportionate to the knowledge gained. Following the student feedback, the Flickr and Diigo activities were replaced by Moodle Database, which essentially performs the same image and web page sharing functions, and the Moodle chat activity was removed. Given the importance of incorporating discussions in a good learning design, the Forum activity was retained, but the number of discussions was reduced. The number of internet search activities was also reduced. The lessons learned were developed into a Best Practice Guide for teaching aquaponics [61], and a Toolbox of Innovative Didactic Practices [62] that is relevant to any PBL curriculum that is taught using e-learning or blended learning.

Not all of the students completed all 15 modules of the aquaponics curriculum. This was particularly apparent at those institutions where the curriculum had been offered as an optional activity, alongside the students' regular coursework, rather than being offered as a credit-bearing elective course. As spring progressed into summer, and faced with competing deadlines at the end of the academic year, some students abandoned Aqu@teach in order to focus on their other assignments. Aqu@teach may therefore be more suitable for compact delivery, rather than for parallel delivery with other courses. The Creative Commons NonCommercial-ShareAlike licenses of the Aqu@teach resources mean that teachers can modify the curriculum to suits their needs, stripping out activities and indeed entire modules that are not deemed to be essential.

Discussion

There is a need for strong and effective interaction between pedagogy and technology to ensure that both are used to best effect in implementing PBL in a virtual environment [63]. In education it is often taken for granted that technologies can 'enhance learning' and the term 'Technology Enhanced Learning' (TEL) is increasingly being used in Europe and other parts of the world to refer to the application of information and communication technologies to teaching and learning [64]. Since the 1990s there has been considerable growth in the adoption of technology within higher education but, despite the widespread growth in practice, concerns continue to be expressed about the extent to which it is being used effectively in order to improve the learning experience of students [65]. The sharing of 'good practice' and 'lessons learned' among members of the higher education community, which can help teachers to concentrate on effective uses of technology and to avoid the unnecessary duplication of effort and expense, has become even more urgent due to the need to move to online teaching during the COVID-19 pandemic. The pilot run of the aquaponics curriculum confirmed the findings of others: adding too many technologies to support teaching and learning, especially where one or two can do a job well, can overwhelm a student [65, 66]. Students are efficient technology users, and are interested in getting jobs done, simply and conveniently. Resources are sought quickly, and students rarely look beyond the first page of results of a Google search [67, 68].

Applying technology enhanced learning within established pedagogic models can be problematic, because the technology gets manipulated to suit the existing pedagogy, and thus only a small portion of the learning and teaching potential of the technology is realized. The technology confronts an existing pedagogical model, and gets consumed by it. The currently dominant modes for e-learning within higher education—those enabled by commercial learning management systems (LMS) and virtual learning environments (VLE)—are generally failing to engage with the rich potential of the digital environment for learning. While they may be widely used, their full range of learning and teaching potential is seldom realized. VLEs such as Moodle have the potential to transform learning and teaching as they can enable any time anywhere peer collaboration through their discussion facilities, and yet they continue to be largely used as repositories for storing lecture content. Their logistical rather than participatory use thereby reaffirms traditional, transmissive modes of teaching [69, 70].

Aqu@teach takes full advantage of the Moodle activities to provide the three types of interaction that are required for effective learning—learner-content, learner-instructor, and learner-learner. The ability to interact can be argued to be analogous to being connected, and for an online learning experience, interaction is perceived to be the defining attribute for quality and value. Instructional scaffolding is used to support the students throughout the learning process, through formative assessment of assignments and interim quizzes. Sharing definitions in the Glossary and resources in the Database, and the use of Forum, Workshop and Wiki activities, creates a community of learning that further supports the students as they progress through each module [6].

The notion of inclusive curriculum [71] has been around for a number of years and is often understood as access to the curriculum for differently abled students, or decolonising the curriculum to enable students to engage with a greater diversity of thought within their disciplinary context. As an increasingly diverse student population chooses to face the financial burden of higher education because of its promise to lead to a good career, the notion of inclusive curriculum needs to expand from a focus on disciplinary content to the skills, competencies and experiences that students can gain through the learning process. According to the Global Skills Gap report, employers are looking for graduates with transferable skills, the most important of which are problem-solving, teamwork and communication. It also recognises the important role of universities in supporting the development of these competencies through both extra-curricular opportunities and active learning [72]. The applied and dialectic nature of student-centred PBL can benefit multi-ability student groups, by enabling both academically and practically minded learners as well as neurodiverse students to engage with a curriculum in ways that passive academic learning may not allow. They can therefore be considered a more inclusive range of pedagogies that also enable students to develop skills for success. Quality, modern higher education must also equip graduates with the critical thinking and problem-solving skills necessary for engaging with and addressing current and future socio-economic and environmental issues. The Aqu@teach curriculum embodies all of these principles in its design and delivery.

Aqu@teach: The Experiment

The pilot testing of the aquaponics curriculum afforded an opportunity for the students to conduct an experiment concurrently using the aquaponic systems at the University of Greenwich, the Technical University of Madrid, the Zurich University of Applied Sciences and the Biotechnical Center Naklo. The experiment enabled the teachers to introduce an element of experiential learning, where learning occurs when students use hands-on, task-oriented activities and relate previous knowledge in a contextual way to a real-life situation. Kolb's [73] theory of experiential learning describes learning as a cycle that includes participants experiencing an abstract concept (Concrete Experiences), investigating the concept (Active Experimentation), reflecting on the experience (Reflective Observation), and generalizing how the concept works and relates to a previously established concept (Abstract Conceptualization). The learners must become immersed in the total experience to complete the experiential learning cycle.

Experiment Design

A standard operating procedure (SOP) was drafted to ensure that the experiments were carried out as uniformly as possible in order to allow for the comparison of results, and an Excel spreadsheet was created for recording the results. The SOP included a system monitoring plan, a planting schedule, and fish welfare and feeding rules. The attributes of the aquaculture part of the aquaponic systems and the cultivation types of the hydroponic part used are shown in Table 11.4. The experiment ran over 5 weeks from 1 April to 7 May 2019. Lettuce (Salanova Hawking RZ 79–135) and spinach (Spinat Kolibri F1 RZ 51–710) from Bigler Samen AG, Switzerland, were used because of their relatively short cropping cycle and suitability for cultivation in spring. The seedlings were produced on rockwool cubes and partially in organic soil. The plants were then planted in the systems as shown in Table 11.4. UPM and ZHAW also grew lettuce and spinach (intercrop) in hydroponic solution (HP D), while UL/NAKLO and ZHAW also grew lettuce and spinach (intercrop) in organic substrate (soil), in order to allow comparisons between plants grown in organic soil, aquaponic and hydroponic nutrient solution.

Table 11.4 Aquaponic system attributes at the University of Greenwich (UG), Biotechnical Centre Naklo (UL/NAKLO), the Technical University of Madrid (UPM) and the Zurich University of Applied Sciences (ZHAW), and the crops grown during the experiment

	Aquaculture part of the system						
Partner	System water volume (l)	System area (m^2)	Number of systems	Fish tank water volume (l)	Fish species	Average fish size (g)	Stocking density (kg/m^3)
UG	6000	18.8	1	1680	*Oreochromis niloticus*	122	5.6
UL/NAKLO	6000	15	1	3000	*Cyprinus carpio*	2500	11
UPM	300	1.2	3	230	*Oreochromis niloticus*	100	5
ZHAW	4200	27	3	3000	*Oreochromis niloticus*	800	15

	Hydroponic part of the system
Partner	Cultivation type
UG	Raft, deep water culture
UL/NAKLO	Raft, deep water culture
UPM	Plant table with channel, nutrient solution flow
ZHAW	Plant table with raft, nutrient solution flow

		Crops and cultivation method	
Partner	System	Crop	Cultivation method
All	AP A	Lettuce and spinach	Intercrop
All	AP B	Lettuce	Monocrop
All	AP C	Spinach	Monocrop
UPM ZHAW	HP D	Lettuce and spinach	Intercrop
UL/NAKLO ZHAW	Soil	Lettuce and spinach	Intercrop

The students were asked to measure a number of parameters during the experiment, as set out in the SOP. Air temperature and air humidity were to be monitored continuously or measured regularly with a handheld multi-electrode meter. The measurement of system water chemistry was done either with spectrophotometry, LCK tests, paper kits or quick tests. The following parameters were analyzed in the system water of each system: NO_2^--N, NO_3^--N, NH_4^+-N, P-PO_4^{3-}, B, Cl-, S-$SO4^{2+}$, K+ , Fe, Ca^{2+}, Mg^{2+}, water hardness, water temperature, pH, dissolved oxygen and electrical conductivity. The water samples were to be taken every second week, i.e. at the beginning, in the middle and at the end of the experiment, from the fish tank, hydroponic inflow and hydroponic outflow. In addition, the students were asked to take pictures of all stages of the experiment (system design, fish, plants, sampling, and activities) and to keep a daily lab diary (e.g., seeds sown, seeds germinated, seedlings transplanted to the system, problems with the fish/system water, etc.). The fish biomass gained and the amount of fish food used during the experiment was measured, and the following parameters were measured for 12 lettuce and/or 12 spinach plants: length, fresh weight and dry weight of shoot and root, and shoot chlorophyll content.

The tasks were divided into five sets:

- Set 1: System monitoring: greenhouse air temperature, humidity and solar radiation; water parameters (electrical conductivity, pH, dissolved oxygen, temperature)
- Set 2: Water chemistry 1: NH_4-N, NO_2-N and NO_3-N
- Set 3: Water chemistry 2: P-PO_4, K, Cl, S-SO_4, Ca, Mg, K, Fe, acidity
- Set 4: Fish welfare, biomass and feeding
- Set 5: Plant growth.

The concept of 'T-shaped skills' was followed during the experiment (Fig. 11.4), whereby the vertical bar of the T represents the depth of skills and expertise in a single field, and the horizontal bar is the ability to collaborate with peers in different fields and to apply knowledge in areas of expertise other than one's own. At each institution, the students therefore measured all of the parameters together as a group (horizontal bar of the T), and each student then took responsibility for investigating

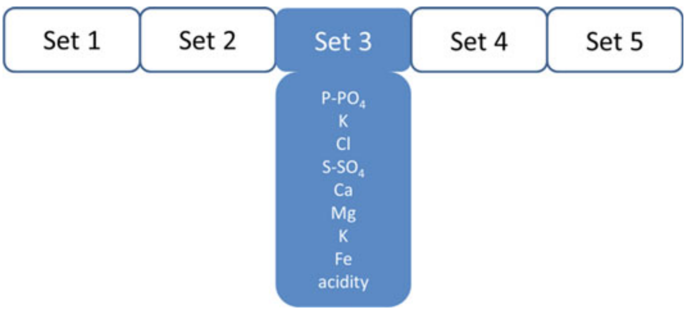

Fig. 11.4 Monitoring tasks for a Set 3 student

one set of parameters in detail (vertical bar of the T), with the intention that they would discuss their results with the students at the other institutions responsible for the same set of parameters. A LinkedIn group was set up to facilitate this.

Experiment Evaluation

Based on the observations of the development of the seedlings as well as the results of the plant root and shoot biomass, it was clear that the lettuce was much more suited for cultivation in aquaponic and hydroponic systems than the spinach, and that fish stocking density, nutrient concentration and biomass production are positively correlated. However, although the SOP described in detail how the experiment should be set up and run, it was not strictly adhered to by all of the student groups. Air temperature and humidity, which are needed in order to take greenhouse conditions into account when comparing plant growth and water parameters, were not measured every week, and neither was the water chemistry (total inorganic nitrogen, electrical conductivity, pH, water temperature and dissolved oxygen). The use of different aquaponic systems, fish species, and stocking densities, as well as the lack of documentation on system monitoring by some of the students, therefore made a global scientific evaluation of the results impossible.

Discussion

When the replicated experiment was originally conceived, the plan had been to use the same fish species, the same fish stocking density and the same type of lettuce planted at the same densities, in order to investigate whether different types of aquaponic systems produce different results. For example, the system at the University of Greenwich is in a rooftop greenhouse in a temperate climate, while the system at the Biotechnical Centre Naklo is in an unheated polytunnel in a continental climate. However, for practical reasons this was not possible in all cases. For example, the cooler temperatures of the Naklo polytunnel meant that carp had to be used instead of tilapia, which requires temperatures of 27–29 °C.

It is clear with hindsight that the students, who were final year undergraduates or first year postgraduates, and therefore expected to be able to act with independence and confidence, should have been supervised more closely, to ensure that the SOP was followed and the parameters were correctly monitored and recorded. While the students enjoyed working on the practical tasks, once again the student groups that fared worst were those that were doing Aqu@teach as an optional course, rather than as a credit-bearing elective. Nevertheless, the experiment afforded the students with a unique opportunity to apply the theoretical knowledge gained from the aquaponics curriculum, to consolidate their learning, and to achieve high cognitive levels.

Aqu@teach: The Summer School

A five day entrepreneurial skills summer school was held at the Biotechnical Centre Naklo in Slovenia in July 2019 with the objective of introducing the necessary entrepreneurial and transversal skills for setting up an aquaponics business. The summer school was attended by the students and staff from the five institutions participating in the project, and the lecture content and exercises were subsequently elaborated and developed into a supplementary Moodle module and accompanying textbook [8]. The Entrepreneurial Skills module (60 h, 2 ECTS) uses the same student-centred activities employed in the aquaponics curriculum—Glossary, Database, Wiki, Forum, and Workshop—and the majority of the activities involve student teamwork in order to reflect the reality of setting up a business, since this is rarely a solo endeavour.

Summer School Curriculum

The curriculum for the summer school was developed following two surveys: a survey of aquaponics companies in Europe and further afield, in order to get a broad overview of the skills that are important in the first few years of a business; and a survey of European higher education institutions which teach subjects where aquaponics could be incorporated into the curriculum, in order to ascertain which entrepreneurial skills are pertinent to those disciplines [6].

The curriculum adopted the lean start-up methodology [74] to introduce the main processes involved in developing a business idea into a start-up company, with lectures and group exercises delivered by aquaponics entrepreneurs and experts in marketing, financing and branding, and a field trip to a local fish farm. The first day of the summer school involved lectures on the factors that can cause start-ups to either thrive or fail, first-hand experience of an aquaponics start-up, and a panel discussion on start-up experiences. The students from each institution gave a 10 min presentation on the results of the Aqu@teach experiment, which led to a discussion about what ‘optimal performance’ means, and how to achieve this. They were then divided into five multinational groups of five students (one from each partner institution) in order to discuss and decide on a business idea.

During the rest of the week the lectures—on the different stages involved in developing a business idea, types of business model, ways of financing a start-up, how to develop marketing, distribution and pricing strategies, and how to present a business idea to potential investors—were interspersed with exercises where each student group worked on developing their business idea using lean start-up methodology tools such as Business Model Canvas, customer segmentation, and Value Proposition Canvas. The summer school culminated with each student team giving a start-up pitch to a panel of nine judges made up of local business owners, university lecturers and public servants. Each student also had to submit a brief report on their business model and marketing strategy.

Summer School Evaluation

The student groups' business ideas were varied and original—a hydroponic extension for aquariums for growing herbs in private households, nursing homes, and schools; a 'design and build-it-yourself' modular aquaponic system with an interactive video game and app for children aged 3–10; an app and sensors to enable remote monitoring and problem-solving of domestic aquaponic systems; supply and maintenance of specialized aquaponic systems for horticultural therapy; and a restaurant with its own aquaponic vine production. The students took the start-up pitch challenge very seriously, and the panel of judges was impressed by how much they had learned in just five days.

The student feedback on the summer school was favourable. They found that it consolidated their previous learning, both from the aquaponics curriculum and the experiment, and they enjoyed applying their knowledge during practical exercises in multinational groups. Regarding the aquaponics curriculum, the students realised that the internet searches that they had previously thought to be too time consuming had, in fact, been worthwhile, in particular those which had been aimed at developing their commercial awareness. They also realised that some of the modules which they had previously thought to be tangential to the curriculum, such as Module 13–Urban agriculture and Module 15–Social aspects of aquaponics, had in fact furnished them with many potential business ideas. Regarding the experiment, the presentations of the results and the subsequent discussion about optimal parameters brought home the importance of monitoring these regularly.

Discussion

Aqu@teach was an ambitious project to develop an innovative higher education curriculum that would equip students with expert knowledge and skills on a multi-disciplinary subject, as well as digital, entrepreneurial and transferable skills that would provide them with a competitive advantage in the labour market. While it was originally conceived as either an online or blended learning course, our experience during the three phases of curriculum development—the pilot run of the aquaponics curriculum, the experiment, and the entrepreneurial skills summer school—lead us to conclude that the blended approach is more satisfactory from the students' point of view, since they value face-to-face interaction with their peers and with their teachers, and classroom time is an invaluable opportunity for teachers to dispel any misconceptions, reinforce the rationale for asking students to perform certain exercises, and engage in in-depth discussions.

The COVID-19 pandemic has forced widespread, rapid and potentially long-lasting change to modes of teaching and assessment. The closure of universities resulted in emergency online teaching, typically in the form of pre-recorded lectures delivered by video conferencing. Anecdotal evidence from around the world suggests that student satisfaction is at an all-time low, since the online experience was not deemed to be effective compared to conventional face-to-face classes. Indeed, effective learning conducive to knowledge building depends on the active participation of learners. While many universities are now planning to adopt a hybrid model, where teachers deliver a lecture and some students participate in person while others participate online, this is a golden opportunity for educators to reflect on how they might make lasting changes to their teaching practice, rather than returning to the status quo (the standard lecture, regardless of whether it is delivered in hybrid or face-to-face mode). With a blended learning approach, the social constructivist pedagogy behind Moodle's design enables students to create knowledge within a social environment, rather than being given knowledge through instruction. The different activities encourage students to use different ways to engage with the course content, and different ways to interact and express themselves. This inclusivity enables multi-ability student groups to engage with the curriculum in ways that passive academic learning may not allow.

Conclusions

As an increasingly diverse student population chooses to face the financial burden of higher education because of its promise to lead to a good career, it is essential that universities recognise their responsibility—to both students and society—in preparing students accordingly for the world beyond, by designing inclusive curricula through which all students can engage in and benefit from learning experiences that develop a range of transferable competencies. Universities also have responsibilities for accelerating pedagogical innovation to enable a more sustainable future, which can be addressed by embedding the concepts of sustainable development and the circular economy in curricula. As a NBS which addresses a number of socio-environmental challenges, including food and water security, water pollution, human health, and climate change, aquaponics makes a good case study for introducing these issues to students, whether it is by focusing on aquaponics as a sustainable food production system, or by focusing on closing the material and energy loops in aquaponic system design.

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Chapter 12
Recommendations for Promoting Environmental Education Through Nature-Based Solutions (NBS) Perspective at Turkish Higher Education Institutes

Hasan Volkan Oral

Abstract Circularity and Nature-Based Solutions (NBS) are relatively recent research areas in Turkey. Scholars have been debating these issues for the last five years, and any scientific studies on these issues in Turkey have not met the expected standards or levels. In contrast to NBS and circularity, environmental or ecological education (EE) is a well-known topic in Turkey. There have been adequate scholarly research on EE from the early 1980s to the present. The purpose of this study is to provide recommendations for increasing EE via NBS at Turkish higher education institutions that have recently attracted a substantial number of overseas students. Furthermore, due to number of limited researches in the literature, the study intends to fill a large gap in the literature both for Turkey and Europe. Finally, within the context of the research, the following recommendations have been made: Launching simulation model training at NBS undergraduate degrees, opening with university elective courses on EE and NBS degree curriculum content, motivating Turkish graduate students to participate in the International Exchange Program (IEP) and NBS training Schools.

Keywords Environmental education · Environmental citizenship · Environmental sciences and engineering · Circularity · Nature-based solutions · Higher education · Turkey

Introduction

Turkey is ranked among the top 10 countries in the world favored by foreign students in 2018. Turkey Higher Education Organization (CoHe) [1] reported that the number of international students in Turkey, which was 48,183 in 2014, increased by two and

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Table 12.1 Number of international enrolled students at Turkish higher education institutes by years (*Source* [5])

Number of ınternational enrolled students	Years
0	1996–2001
50,000	2001–2005
100,000	2005–2010
150,000	2010–2015
200,000	2015–2020

a half times in 2018 reaching 125,138. Turkey was among the first 10 countries in the world to attract the highest number of international students [1]. The growing number of foreign students from 2004 onwards means a shift in scope and practices concerning the internationalization of education in Turkey. The possible reasons for this growth can be related to launching international programs in educational institutions in the 1990s. In other words, the internationalization of education in Turkey was essential to foreign policy in the 1990s [2]. Dziwornu et al. [3] also reported that Turkey has made significant investments in the emerging economy over the years. For instance, in its education sector, Turkey offers scholarship opportunities to attract students from other emerging and developing economies. Consequently, in the academic year 2000/2003, out of 1,256,629 tertiary students, 15,719 were international students. The proportion of international students in Turkey increased to 26,000 foreign students in the academic year 2010–2011 [4]. Policies and measures to be introduced by the Turkish Government balance the distribution of scholarships to foreign students from countries located in the Caucasus and Central Asia to the Middle East and Africa. The result of this wide spectrum is noticed on the rise in international student enrolment since the 1990s. Table 12.1 presents the data on the number of international enrolled students from 1996 to 2020 [5].

A few Turkish researchers [6–10] have studied the EE (EE) at Turkish Elementary or Primary Schools. Yildiz [6] reported that environmental awareness is the main starting point of the EE programs at Turkish elementary schools, and Alkis [7] investigated the EE in Turkey relevant to Education for Sustainable Development (ESD) perception. According to Yildiz [7] as the first step, this perspective is needed to be understood by the educational staff at Turkish schools first. Alp [8] conducted a study about elementary school students' environmental knowledge and attitudes and they revealed that Elementary school students' behaviors toward the environment were independent of their knowledge of environmental issues. Genc [9] has investigated the effect of project-based learning on students' attitudes toward the environment with 39 students, and concluded that students believed this practice helped them to define environmental problems more clearly and take on more active tasks in the solution process. According to Ardali [10] the Turkish Environmental Non-Governmental Organizations helped to increase the environmental awareness in the society with the help of EE campaigns at schools.

As a result of the literature review, only a few Turkish researchers [11, 12] have focused into the state of EE and citizenship in Turkish higher education institutions. For instance, Hamalosmanoglu [11] focused on the teaching methods, features, and place of EE in various subject areas and science education lessons, which are taught in Turkish primary and higher education institutions, while Oral [12] investigated the perception and behavior levels of environmental citizenship of Turkish university students between the ages of 18–25. Oral [12] mentioned the concept of environmental citizenship, which is also defined by a COST Action Project known as the European Network for Environmental Citizenship (ENEC) [13]. According to ENEC [13]: "Environmental citizenship is characterized as the responsible pro-environmental conduct of citizens who, through individual and collective action, act and participate in society as agents of change in private and diverse societies, on a local, national, and global scale, to solve contemporary environmental problems, preventing the creation of new environmental problems, and achieving their goal".

Nature-Based Solutions (NBS) is a broad term, and several researchers have studied its different aspects. For instance, Kabisch [14] have studied the relationships between NBS and climate change mitigation and Wamsler [15] also discussed the possible ways to overcome the barriers between NBS and climate change adaptation. Frantzeskaki [16] offered some strategies to imply NBS relevant to urban plans and Oral [17] presented a critical assessment based on case studies and literature for NBS, which are relevant to water management in European cities. Keesstra [18], assessed which NBS could become the norm for land management strategies. Potschin [19] also stated that NBS can offer a sustainable way to deliver several ecosystem services, such as biodiversity conservation, sustainable use of natural resources, and ecosystem protection. A small number of scholars, on the other hand, have performed studies to determine the relationship between NBS and EE. For instance. Song [20] has only illustrated an example to answer the following question: "How EE through ecological art can help students develop creativity, critical thinking, and an arts-informed notion of being a citizen of the World?".

The key terms "nature based solutions," "Environmental Education" AND "ecological education," and "environmental citizenship" were used to search the literature in scientific databases Google Scholar, ResearchGate, Academia.edu, ScienceDirect, and Scopus. The search was conducted in both Turkish and English languages. According to the survey results, some private consulting firms [21] and Turkish state universities [22] conducted training courses aimed at promoting NBS's core definition. When the course materials are examined, it is clear that the contents are not particularly scientific, with the majority of them relying on common mainstream media outlets rather than scientific sources.

As a result, the primary goal of this research is to deliver recommendations for promoting EE through NBS at Turkish higher education institutions, which have recently attracted a large number of international students. In particular, a scientific study conducted in Turkey on this subject could not be found in the literature review. Therefore the secondary goal is to fill a gap in the literature that is significant to Turkey and Europe.

The study's organizational structure is as follows: Sect. "The Main Concepts of EE" introduces the key concept of EE, Sect. "The Framework of NBS" describes the NBS context, Sect. "Recommendations for Promoting EE Through NBS at Turkish Higher Education Institutes" highlights recommendations for promoting EE in Turkish Higher Education Institutes from an NBS perspective, Sect. "Challenges and Opportunities" explains the challenges and opportunities, and Sect. "Conclusion" summarizes the study's main findings.

The Main Concepts of EE

EE is closely connected with sustainable development. This relationship can, however, be obtained in many ways. Sustainable development is described by some academics as the ultimate aim of EE: the word 'EE' is proposed for sustainable development (EFSD) [23]. Other scholars prefer to mention that sustainable development refers to specific objectives that should be added to those of EE: therefore, they use the term "EE" and "sustainable development" [24]. Today, United States Environmental Protection Agency (EPA) [25] highlights that EE increases public awareness and knowledge about environmental issues or problems. Ardoin [26] defined the EE as follows: "EE encompasses approaches, tools, and programs that develop and promote environmental attitudes, values, awareness, knowledge, and skills that prepare people to take informed action on behalf of the environment." There are also five main components of EE that can be listed as follow [27]:

- Awareness and sensitivity: Being sensitive to environmental events
- Knowledge and understanding: Using and evaluating existing knowledge to understand environmental problems
- Promotion of positive attitudes: An effort to tend to solve environmental problems
- Skills development: Creating and implementing proposals to solve these problems
- Improved inclusion: Taking action against problems, implementation

The Organization for Education, Science, and Culture of the United Nations (UNESCO) [28] states the environment as a system calls for the development of systemic thinking. By analyzing the components and relations of the environment as an "eco-socio-system", one can gain a global understanding of environmental realities and thus have the necessary inputs for sound decision-making, and this is where ecological education comes into play. This type of education involves learning about the diversity, richness, and complexity of one's life. Furthermore, ecological education has the potential to play a critical role and calls for a shift in educational policy toward ecologization, and this type of education will provide key elements to students in order for them to find solutions to environmental problems such as limited land resources, production wastes, insufficient knowledge and application of natural development laws by humans, and shortcohorts [29].

Some of the significant benefits of EE are also explained by Tillbury [30] as follow:

- EE provides a holistic curriculum approach; Combines and develop scientific inquiry and social science thinking.
- Teaching values; The cognitive domain does not activate the decision to engage in the enhancement of the environment but relies on personal encouragement and a sense of duty due to the creation of personal environmental ethics.
- Environmental action; EE generates action by challenging students to alter aspects of their lives at a personal level so that they are interested in a more sustainable lifestyle. At the public level, they are encouraged to take responsibility for environmental care and management, either directly through involvement in realistic conservation programs or indirectly, through the political process, as well-informed and responsible adults.

Develops critical thinking skills; Rawls [31] explained critical thinking as; the characteristic set of principles for the utilization of basic rights and duties and the perseverance of the proper distribution of benefits and burdens of social cooperation. Eropean Union (EU) [30] developed this definition as emphasized that critical thinking allows to students learn to critically examine the main political disputes over environment and development problems and the differing value positions which underlie these disputes.

The Framework of NBS

EU [32] has defined NBS as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions". The main objectives of the NBS are enhancing sustainable urbanization, restore degraded ecosystems, climate development, launching change adaptation and mitigation, improving risk management, and resilience [33]. Moreover, NBS can be counted as a multidisciplinary, integrated approach to address societal challenges and some natural hazards effectively and adaptively, simultaneously providing human well-being and biodiversity benefits [12]. According to International Union for Conservation of Nature (IUCN) [34] some of the significant preliminary principles of NBS, which also define the frameworks of NBS, are:

- Technological and engineering solutions may be discussed as methods to overcome the social limitations of NBS.
- NBS preserves the diversity of biology and culture and the potential of habitats to grow over time.
- NBS can be applied at a landscape scale.
- NBS recognizes and discusses the tradeoffs between the production of a few immediate economic growth benefits and future options for the production of a full range of ecosystem services.

Recommendations for Promoting EE Through NBS at Turkish Higher Education Institutes

This section explains and shows the recommendations for promoting EE at Turkey's Higher Education Institutes. The organization of the Turkish Higher Education Institution is discussed in the first sub-topic, and the recommendation methods are presented with examples in the second sub-topic.

The Structure of the Turkish Higher Education Institutes

The higher education system in Turkey is supervised by the CoHE [35]. Turkish universities offer the following programs for students from Turkey and overseas:

- Associate degree programs
- Bachelor's degree programs
- Graduate programs
- Postgraduate programs.

Higher education institutions in Turkey are generally divided into three groups: state universities, private or foundation universities. There are 84 private universities and 109 public universities in Turkey [1]. Universities, institutes, and faculties are covered by the law, which have four-year curricula, while the CoHE offers two-year vocational schools.

Specialized education in many fields is provided by the state universities of Turkey. To gain entry into the degree programs offered by the Turkish state universities, students must have completed secondary/high school education. Turkey's higher-level vocational schools emphasize unique vocational education and training. These institutions of higher education offer two-year studies and train students for an associate degree (pre-degree).

Private and foundation universities are funded by private foundations and are governed by the state, according to the standards and procedures established by legislation. These universities are state-run and controlled and are, by definition, non-profit. They are made up of institutions and departments which carry out educational and research programs. Bachelor's, master's, and doctorate of philosophy (Ph.D.) degrees are available from such institutions. Associate degree programs are also available via technical schools [36].

The following are the details of the programs offered by private and foundation universities:

- **Programs of Associate Degree**: The duration of associate degree programs is 2 years. Vocational high school graduates may qualify for associate degree programs without taking any centralized exams.
- **Bachelor's programs**: Bachelor's degree programs generally take 4 years to complete. Specialized degree programs such as medicine (6 years) may be longer.

- **Graduate Programs**: Turkish universities offer various types of graduate programs. Master's programs usually last about 2 years (master's programs without thesis generally take 1 and half years),
- **Post Graduate Programs**: Most state and private universities are offering postgraduate programs depend on their educational capabilities.

According to Study in Turkey [36], the following education institutes are forming the general structure of the Turkish Higher Education System.

- **Faculty (College)**: A division of higher education, research, and publication. Various departments and programs may be linked to it. Students are awarded a Bachelor's degree at the end of an education program that lasts for at least four years.
- **Graduate School**: A university institution concerned with graduate education, scholarly research, and applications. Graduate Schools are awarded Master of Arts (MA), Master of Science (MSc), or Philosophy of Doctorate (Ph.D.) degrees.
- **4 year School**: An institution of higher education that is mainly concerned with providing instruction for a specific profession. The duration of the program is eight semesters.
- **Conservatory**: A higher education institution in which music and performing arts students are educated by artists. It has a length of eight semesters.
- **Post-Secondary Vocational School**: A higher education institution aimed at educating human skills in particular professions and offers four-semester instruction.
- **Research and Application Center**: A higher education institution that carries out research and applied studies to meet the needs of the different fields of applied studies and to provide preparatory and support activities for the various professional fields and to support higher education institutions.

What Are the Ways to Improve EE Through NBS Perspective at Turkish Higher Education Institutes

In Turkish Higher Education Institutions, which include state universities, private universities, and foundation universities, providing EE and NBS perspectives in a way that complements each other should be accomplished through a case-based education system. Case-based education definition is generally used across a wide range of disciplines, and collections of validated cases are available online, often with handouts, readings, assessments, and tips for teachers. Cases range from scenarios that can be addressed in a single sitting, sometimes within minutes, to sequential or iterative cases that require multiple settings and learning activities to achieve multiple valid outcomes. They can be taught in a one-to-many format using polling technology or in small teams with group reports [37].

The recommendations proposed under this section are mainly based on raising awareness and capacity building, which is relevant to environmental raising awareness; UCF [38] revealed that environmental awareness makes people realize there is an urgent need to identify immediate action to stop harming the environment and to start restoring the damage they have done to it. There is no action or at least no proper action unless there is awareness, and this action must start at the individual level and also be spread through the people and organizations.

As for the capacity building, this term is needed to use with environmental sustainability. Basu [39] reported that a key characteristic of environmental capacity development is its cross-cutting, multi-sectoral nature. To be successful, capacity building should be integrated into multiple development sectors, going beyond "traditional" environmental management functions.

Launching Simulation Model Training at Bachelor's Degree Courses Relevant to NBS

Forsythe [40] suggested that a novel approach to learning in construction technology courses is presented by the physical modeling game. Concerning audio-sequential learning, this attempt taps into visual-spatial learning, thereby providing a complementary but separate way of learning. The game also provides the advantage of direct interaction, which can not even be accomplished through observation-only site visits. Before Forsythe [40], some researchers [41, 42] already discussed the benefits of the simulation model training courses. According to Al-Jibouri [41], a simulation model contains many of the aspects of a real project including planning, decision-making, uncertainty, environmental effects, finance, and a realistic physical model of the project and resource operation. In addition, Lateef [42] stated that simulation-based training techniques, tools, and strategies can be applied in designing structured learning experiences, as well as be used as a measurement tool linked to targeted teamwork competencies and learning objectives. Based on these recommendations, Turkish higher education institutions might be able to provide simulation model training courses for NBS. For instance, one of the best known NBS on-site models is constructed wetlands [43, 44] and green roof-surfaces [45]. Figures 12.1 and 12.2 present these NBS application models in three-dimensional (3D) form.

Opening University Elective Courses at Bachelor's Degree Curriculums About EE and NBS

"EE" courses should be open in educational institutions at Bachelor's degree level as departmental electives, faculty electives, or University electives. Elective classes can count toward a student's degree but are not specifically related to the student's degree program.. The student may take elective courses to supplement his or her degree or to pursue another topic he or she is interested in [48]. To ensure or encourage students to take these courses, it may be necessary to keep the European Credit Transfer

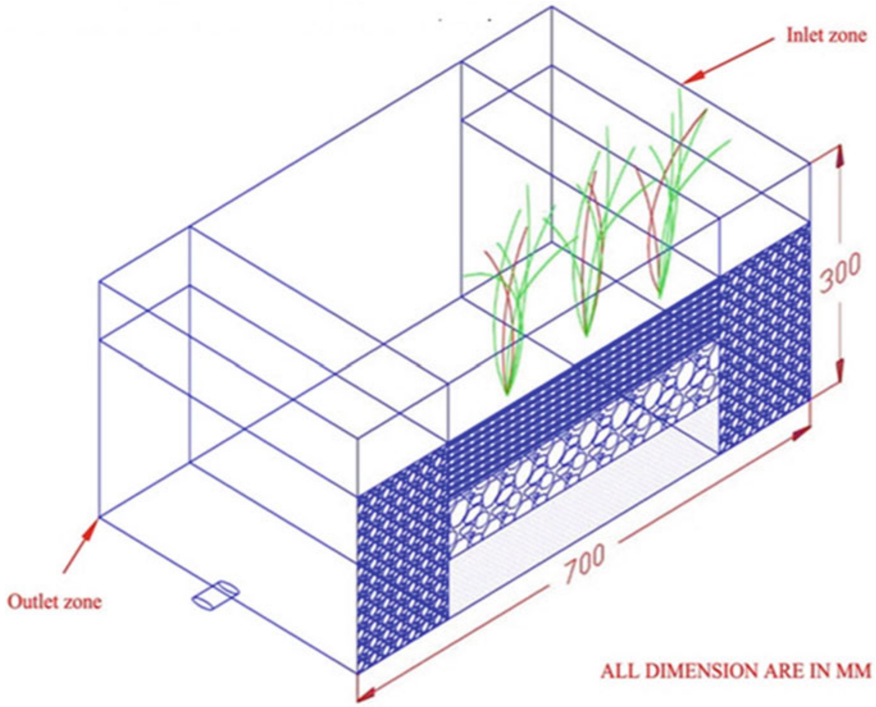

Fig. 12.1 A 3D simulation model of constructed wetland (modified from [46])

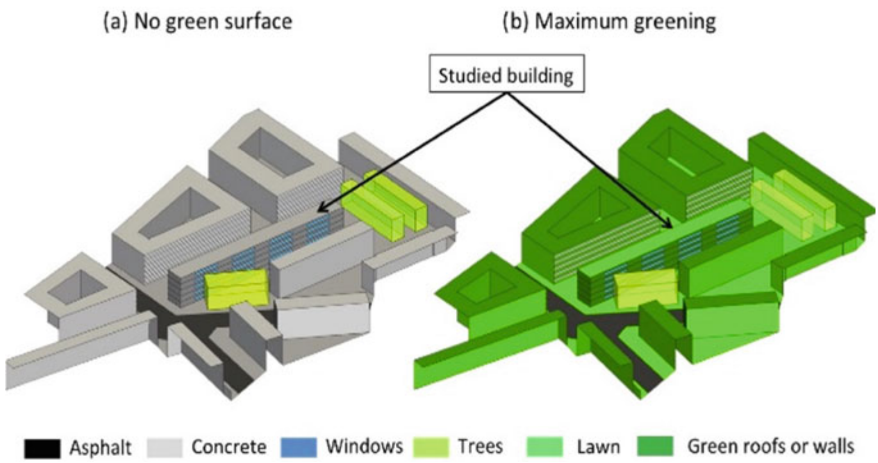

Fig. 12.2 3D models of green surfaces [47]

System (ECTS) value of the course higher than other elective courses. If these courses cannot be opened, then other courses on environmental issues can be opened in the course title. For example, opening courses such as "Fundamentals of Sustainable Development" should be encouraged by the relevant institution management. The most important point to be considered here is that the course contents are prepared in an interdisciplinary structure.

Interdisciplinary approaches are not only necessary for a student to learn any particular discipline or synthesize the problem, but also enrich the lifelong learning habits, academic skills, and personal growth of students [49]. There is one concrete example, which supports this suggestion. As an elective university course, "Fundamentals of Sustainable Development (INE 362)" is offered, with a syllabus that includes a subject called "NBS and Circularity Assessment" (Fig. 12.3). The course is taught to undergraduate students from the Faculty of Economics and Administrative Sciences by the Faculty of Engineering in an interdisciplinary framework. The "INE" in the course code stands for "Industrial Engineering" [50].

Theoretical and practical courses in environmental sciences and engineering are offered to undergraduate and graduate students in Turkish Higher Education Institutions' Engineering Faculties, under the Department of environmental engineerings. Turkey also has 30 state universities with environmental engineering departments [1]. Unfortunately, there are no undergraduate or graduate courses related to NBS or circularity aspects in these departments' curricula. Aside from departments of environmental engineering, EE courses are only offered as university electives at a few universities, and there is no mention of NBS in the course syllabuses.

FACULTY of ECONOMICS and ADMINISTRATIVE SCIENCES
POLITICAL SCIENCE and INTERNATIONAL RELATIONS (in English) PROGRAMME
COURSE DESCRIPTION

Name of the Course Unit	Code	Year	Semester	In-Class Hours (T+P)	Credit	ECTS Credit
FUNDAMENTALS OF SUSTAINABLE DEVELOPMENT	INE362	4	8	2+0	2.0	3.0

Weekly Course Contents and Study Materials for Preliminary & Further Study	
Week	**Topics (Subjects)**
1	Brief information about the course schedule: The main frame of the Sustainable Development.
2	Environmental Sustainable Development: Closer look to Environmental Problems: Air Pollution and Control
3	Soil Pollution and Control
4	Water Quality Management and Control
5	Climate Change and Global Warming
6	Sustainable Energy Policy and Planning
7	Energy Efficiency and conservation
8	Renewable Energy Management:Interactions between Sustainable Development and Renewable Energy
9	Social,Environmental and Global Aspects:Global and Regional Assesment
10	Global and Regional Assesment Implications of Sustainable Development pathways for renewable energy
11	Barriers and opportunities for renewable energies for the context of sustainable development
12	The concepts of Green Economy I: Carbon Related mechanisms I:Low-carbon economy, Carbon neutral fuel, Carbon neutrality, Carbon pricing Emissions trading, Carbon credit
13	Nature-Based Solutions and Circularity Assesments
14	The role of governmental and non-governmental organizations

Fig. 12.3 Fundamentals of sustainable development course syllabus relevant to NBS and circularity [50]

Opening Graduate Courses About NBS at Graduate Studies

According to Joyner [51] as a result of this student need, graduate faculty may be given opportunities to give graduate students program advice, job guidance, or personal advice. These privileges go beyond the conventional interaction of graduate student-instructor and are mostly reserved in advisory positions for faculty or staff.

Graduate courses focusing on the NBS subject can be developed in Turkish higher education institutions. If the course is not immediately accessible, it can be added to the engineering sciences syllabus and offered to students for a few weeks. When the graduate courses offered in Turkish Higher Education Institutions were examined, it was discovered that only economic courses covering the subject of circularity were offered under workshops, rather than NBS [52].

Encouraging the Turkish Graduate Students to Attend the International Exchange Programs (IEP) and Training Schools About NBS

The IEP was founded in 1919 as a result of World War I, and it has been strongly influenced by subsequent wars. The program was developed with the goal of increasing international awareness and preventing disasters like the one that inspired it [53], and moreover IEP has a number of advantages as shown at Table 12.2.

Among these IEPs, one of the well known and popular programs is the Erasmus program, launched by the EU, which is one of the most important manifestations of internationalization of education in the world, primarily due to the increase in international mobility of students, lecturers, and administrative staff, as well as the preparation of classes in foreign languages [55].

Furthermore, The International Association for the Exchange of Students for Technical Experience [56], a non-profit organization, is an association of national committees representing academic, industrial, and student interests that provides career-focused professional internships abroad, social and intercultural reception programs, and an international network to students, employers, and academic institutions.

In addition to these exchange programs, there are also scientific exchange programs known as Short Term Specific Missions (STSM) and Training Schools, which are supported by the European Cooperation in Science and Technology (COST) actions. COST actions provide international research funding for researchers and innovators to set up interdisciplinary research networks in Europe and beyond, this can include all fields of science and technology. STSM allow visits between researchers involved in the COST action to training and access to visit an institution or laboratory in another COST Member State. These scientific missions may last up to six months in another COST Member/Cooperating Member or Near-Neighbor Country joining the Action. They aim to foster collaboration in excellent research infrastructures and to share new techniques that may not be available in the home institution or laboratory of the participant [57]. For instance, in CA 17133, which is also known as "Implementing nature-based solutions for creating a resourceful circular city" and funded by H2020, more than 40 researchers, including graduate students,

Table 12.2 Benefits of IEP for university undergraduate and graduate students [54]

Educational	Personal	Long term
International learning and knowledge encourage students to embrace and understand a range of different cultural and community perspectives	Maturity and relational quality of life, driven by the desire to face obstacles beyond the comfort zone and the familiar support network	In almost every sector, prospective employers look favorably at the experience gained while living overseas and knowledge gained from another language and culture
Language acquisition is achieved through practical immersion	Self-development and awareness contributing to higher self-confidence and self-esteem. This is often the most noticeable change for going back, exchange students	Effective curriculum completion is an exemplary indicator of personal flexibility, which requires the ability to negotiate, concentrate and excel in tough times
Awareness and adoption of alternative, multi-faceted approaches to learning	Integration into another family, as well as the formation of long-term friendships, all contribute to a greater appreciation for the home and family	Increased pressure to interact and link with others provides an understanding of group dynamics and personal sensitivity to others
Enhanced interest in global issues as well as a broader general knowledge	Students grow independent thoughts, make educated decisions, and aim for new goals after completing the course, which gives them a profound sense of accomplishment	

found an opportunity to conduct scientific studies all over Europe. Added to that, overseas scientific studies are also supported by the action's budget. COST Actions can also be assisted by training schools to disseminate the information and promote cooperation. Training schools can be organized on relevant research subjects and can provide resources for the events of the action to be disseminated. They provide intensive training within the laboratories and organizations involved in COST Action on emerging research topics. The participants in COST Actions are primarily, but not necessarily, young researchers and Ph.D. students. As part of life-long learning, training schools often cover suitable re-training [13].

As for Turkey, CoHe [1] offers also some IEPs such as the "Mevlana Exchange Program" and "Project-Based International Exchange Program". Briefly, as for Mevlana Exchange Program, it is for all foreign organizations, the curriculum offers an incentive and students of Turkish universities to study abroad. The goal of the program is to facilitate the exchange of students and academic staff between Turkish Higher Education Institutions and higher education in other countries. As for the second exchange program, institutions of higher education establish joint field projects approved by the CoHE Executive Board. The chosen projects are carried out through a student/academic staff exchange. Cooperation between higher education institutions will be facilitated and encouraged by this program. Since 2016, there have been 66 ongoing projects involving 36 Turkish state universities and 28 foreign institutions of higher education.

Challenges and Opportunities

The first challenge is Turkey's lack of NBS experts. This means that no one is eligible to teach or have special courses on NBS. Another challenge is that there aren't enough studies and articles on this subject to be used as course material. Despite the fact that there are numerous tools available on the internet, the majority of them are not in Turkish. Unfortunately, among Turkish university students, speaking and understanding a foreign language other than Turkish, as well as being able to follow publications on this topic, is extremely low [58].

Linked to previous section, international exchange services and programs at Turkish universities are now more extensive than they were previously. Students should take advantage of this opportunity. Academic staff also should take advantage of these opportunities, particularly if they want to expand their knowledge and experience in the field of NBS. Moreover, today's Turkish Higher Education policies include the realization of the entrepreneurial university model. According to Genc [59], this realization leads to university administrations implementing sustainability approaches in environmental, social, and economic aspects, which will result in the opening of more undergraduate and graduate courses related to NBS.

Conclusion

The purposes of this book chapter are to suggest methods to increase EE through NBS at Turkish Higher Education Institutes, which have benefited a large number of international students in recent years, as well as to fill a gap in the literature applicable to Turkey and Europe. The recommendations through NBS put forward for these purposes are briefly as follows: Launching simulation model training at NBS undergraduate degrees, opening with university elective courses on EE and NBS degree curriculum content, motivating Turkish graduate students to participate in the IEP and NBS training Schools. The implementation of these recommendations will take some time, however, and some difficulties will emerge in this process, such as a small number of scholars in this field and insufficient course learning materials.

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Part III
Environmental Education and Social Engagement

Chapter 13
Bees and Society: Native Biodiversity as a Strategy for Environmental Education Based on the Processes of Nature

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Books are the bees which carry the quickening pollen from one to another mind.
James Russell Lowell
Nature is, after all, the only book that offers important content on every page.
Johann Wolfgang von Goethe

Abstract The use of entomological collections in teaching is a way of awakening curiosity in students in relation to biodiversity and has a strong appeal in environmental education. Most of the time, however, the collections are merely demonstrative and do not involve the students in the search to identify the different organisms

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and their role in natural systems. Regarding the social perception that the student should develop in relation to insects, didactic materials need to go beyond identification and classification and involve the students in the relationship between the different insect species and eco-systemic services. The aversion that many insects cause in most individuals is, at times, an impediment to the teaching and learning process in Zoology in regard to Entomology. The proposal of activities that involve an approach based on bees, a species within the Insect class whose representation by society frames it as "friendly" species, is a strategy involving an approach in which the student perceives the social role of insects, in addition to learning about morphological characteristics, structural characteristics, and evolution etc. In this chapter, we shall address Entomology teaching strategies and methodologies involving bees, which could be applied to different groups of students at different levels of formal and non-formal environmental education.

Keywords Environmental education · Urban sustainability · Entomology learning · Terrestrial ecosystems sustainability

Introduction

The teaching of Nature Sciences covers a wide variety of concepts that are often complex and difficult to present due to various contents involving learning processes such as memorization, which hampers the effective understanding of the subjects addressed. In order to improve the teaching–learning process, given that learning is a complex concept associated with distinct processes and factors inherent to the teacher, the student, and the school context, we observe that, in general, it falls on the teacher to renovate their practices with the aim of achieving the proposed objectives and targets. Therefore, it is not only necessary to address conceptual knowledge in the classroom, but also establish with the student the social importance of their learning and of the knowledge acquired. This will promote the development of cognitive and non-cognitive skills and abilities.

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Regarding environmental education in schools, various authors can be found that indicate that behavior changes in relation to the environment integrate cognitive properties and direct affective experiences [1, 2]. This also involves changes in protagonism and the role of 'emotions', which, in this context, is associated with an emotional affinity with nature as a key factor to promote environmental behavior [3, 4].

In this sense, we can highlight the importance of teaching through investigation in the scope of scientific literacy. This means that it is not sufficient to only teach the students the theoretical concepts that are already known and postulated by the scientific community, they should be taught how to acquire such knowledge and understand what it represents for and in society, in addition to stimulating their curiosity to achieve these objectives satisfactorily. After all, the biopsychosocial development of the child occurs through the educative experiences they develop with Nature .

In addition to such aspects, the importance of developing positive emotions for nature while still in childhood is emphasized, in ordkellerer to develop responsibility for the environment [5], with reflections in adulthood.

> Affection for nature underscores the importance of emotions in human existence, as well as the role these sentiments toward the natural world plays in developing theses emotional tendencies in our own species. [2]

Technology has become widespread in education in the form of various tools such as virtual learning environments (VLE), objects of learning (OLs), and other tools, which do not always achieve the desired didactic results. However, despite increasing incentives to use differentiated methodologies that exploit technological mediums, which often do not consider aspects of "observation" in practical activities in the classroom that enable greater approximation to nature, we can, instead, adopt more simple resources that satisfactorily achieve their purposes, helping students in the understanding of scientific concepts.

When at school, the child has contact with and learns about the surrounding nature and the connections that will be developed may be translated through various values: utilitarian, naturalist, ecological-scientific, esthetic, symbolic, humanistic, moralist, mastery, and negative value [7].

Also in relation to environmental education, which should prioritize teaching based on greater approximation to nature, what we observe is the use of images of animals, which, in general, are distant from the reality of the children, such as the polar bear (*Ursus maritimus*) and the giant panda (*Ailuropoda melanoleuca*) [2, 8, 9], while species considered "harmful" to humans do not receive the same moral considerability regarding preservation and protection.

In this context, insects are not "popular" in environmental education activities, especially when they involve the humans *versus* nature relationship. However, the relationship between society and insects is reflected in distinct contexts such as cooking [10–12]; medicine [13, 14]; paleontology [15]; arts and religion [16–18]; and even economics [19, 20]. We can also emphasize the presence of insects in literature [21], especially in children's books, for which there is no research identified that demonstrates changes in behavior, values, or perception of children through reading.

The aversive behavior that society presents in relation to insects is most probably associated with a historical view, which persisted until the middle of the eighteenth century, in which these species did not represent a defined set among animals and plants, being considered "imperfect beings" associated with "spontaneous generation" [22] (p. 114).

> Negative attitudes towards insects manifest as the emotion disgust, which is regarded as a psychological adaptation to produce pathogen-avoidance behavior. [23] (p. 1).

The hypothesis proposed by Almeida [23] involves theories of evolutionary psychology (parasite avoidance theory of disgust and error management theory), and the authors indicate two factors related to increased urbanization and increased intensity and breadth of feelings of disgust in relation to insects:

(1) urbanization increases the extent to which people can see insects indoors, and insects that are seen more often indoors induce stronger feelings of disgust than is induced by insects seen outdoors;
(2) urbanization reduces people's natural history knowledge about insects, and decreased knowledge results in a broader range of insects eliciting feelings of disgust.

Methodological Approach

When we are consigned to teaching about invertebrates, we observe that, in general, many species of insects are viewed with apathy, aversion, and fear by western society, without perceiving the role of insects in natural processes. Regarding children, [24] indicates that when asked to depict an animal, the vast majority draw large four-legged mammals associated only with terrestrial ecosystems, although insects have the greatest diversity among animal species of around 72%, with more than a million known species and a total of 5.5 million estimated species [7, 25].

> The prevailing paradigm of urban development is neither necessary nor sustainable and constitutes more a design deficiency than an intrinsic and inevitable flaw of modem life. [26] (p. 2).

For the teaching of Sciences, Entomology, with a focus on species which children are afraid of and for which there is prejudice, such as insects, demonstrates that we should seek teaching–learning models that seek to approximate children to the processes of nature.

Besides the scientific misconceptions that continue to predominate in the preconceptions of students, the role of didactic books as a learning instrument does not even support the teacher, much less the student, as they do not enable an approximation to the object of learning, insects. When analyzing the content on insects in the didactic books used in the 7th grade of basic education in Brazil, [27] (p. 14) found *a focus* *directed towards harmful aspects, which carried on for decades, with little emphasis on ecological aspects.*

According to [28], there is an inherent affinity between individuals and nature, and this would explain the pro-environmental behavior evident in society. For [2], such behavior is triggered by "biophilia", a concept proposed by Kellert [29] (p. 2), in which *human beings naturally have emotional ties with nature and its living organisms*. Despite being considered controversial, biophilia, as behavior, could be genetically increased through learning and experience [7, 30], which poses an important question for socioenvironmental research, and would demonstrate the effectiveness of teaching based on natural processes, especially in the addressing of themes with strong aversion for students.

In this context, for example, when the academic topic involves "insects", only beneficial aspects are cited, especially those associated with economic factors that involve a single species, such as Africanized honeybees in the production of honey, and the silkworm in the production of silk. Therefore, there is no didactic approach that enables the child to develop critical reasoning beyond repulsion and fear, only an approach that demonstrates how beneficial it is to exploit insects for the benefit of society [27].

However, a superficial approach in relation to the role of these animals in ecological processes such as the food web, among other factors, indicates that we must promote holistic education capable of highlighting the ecological importance of insects.

It is observed that there is no perception of the importance of bees, or of insects in general, when providing ecosystemic services to society. This perception would enable teaching based on the systemic observation of nature, breaking with static models for the teaching of Entomology [31] (p. 5). The conservation and preservation of biodiversity should overcome the negative relationships of society with insects, with the teaching methodologies and strategies developed from the first years of basic education as a platform.

In the Bees and Society Chapter, we shall put a special focus on a group of insects that is universally accepted by society, bees, and from this approach, enable learning situations involving insects both for formal and non-formal education. This strategy involves society's perception of the economic and medicinal value, or the environmental services rendered by bees, which are associated with being a species of insect that is "beneficial" to human beings, to the detriment of other "malefic" insects.

It is a fact that the spread of technology as an educative tool in the form of various tools such as virtual learning environments (VLE), learning objects (LOs), and other technologies, does not always provide the desired didactic results.

However, many simple resources that satisfactorily fulfill educational purposes, helping students understand scientific concepts through the ludic nature of practical activities in the classroom, are often disregarded for methodologies that exploit technological mediums.

For Vygotsky (Cultural-historical activity theory), child development is the result of interactions between children and their social environment. During basic education, in the period between approximately 6 and 14 years old, such interactions include those with parents and teachers, friends and classmates, brothers and sisters etc. Besides personal relationships, social relationships can also involve connections with objects present in their daily lives, such as books, toys, social interaction games, and elements of the urban and natural landscape in the child's routine, which will be present in the main environments experienced by the child, that is, home and school. However, [5] indicate that within the social–historical and cultural context, the child may promote or inhibit biophilia.

The ways individuals establish a connection with the natural world and develop skills for the valuation of nature and/or how they reason morally on environmental degradation, are constructed from the established relationships. Although these connections involve cognitive and moral maturity, it is important to emphasize that children of the same age may not have the same levels of cognitive ability, in addition to the influence of means of communication, which affect environmental sensitivity in the human relationship and have translated into distancing and disinterest of the student in natural processes.

The proposal of the study of insects as a strategy for the improvement of environmental education through solutions based in nature is consolidated as an object of learning addressed in various disciplines on the education curriculum, at different levels, from primary education to higher education, including non-formal education involving local communities. However, what is the motivation to teach/learn about insects and nature, given that society, in general, has a negative representation of these invertebrates?

When we use insects in the classroom, not only through images and figures, we provide the opportunity for students to abandon aversive behaviors, and when using them as a didactic tool we enable the development of skills such as observation, argumentation, criticism, curiosity, creativity, and clarity of expression.

> Direct contact with the insects allows a freer attitude of students and at the same time occasionally favors rapprochement with the teacher. [32].

The applied methodological proposal is an important element of mediation between reality and scientific knowledge in academic investigation, as a way of enriching the students' knowledge in a direction that leads to a more complex and critical view of reality [33] (p. 9).

The experiences involved in holistic learning are not limited only to specific content and the teacher, they open different possibilities for interdisciplinary teaching, which is characterized as a process and not a product [6]. Such a perspective is in accordance with [34], who indicates that practical abilities are developed based on understanding of the environment and in the human connection with it.

Talking circles, initially projected as an instrument for the cross-curricular development of environmental education, have advantages in the context of teaching and learning, as they enable *approximation between subjects in everyday teaching*, establishing an *area of dialogue and interaction* [35]. In environmental education activities, whether in the scope of formal education or non-formal education, talking circles enable the students to access prior knowledge on a given topic (pre-conceptions), as well as opinions and misconceptions, and promote the (re)construction of concepts, values, and attitudes.

Thus, from the understanding and learning on bees and the social role of these insects, the individuals in a community (academic or otherwise) perceive the natural environment while they re-elaborate their social and emotional perception in relation to insects. As a process, learning through experiences with the natural environment promotes the empowerment of the children, enabling them to reflect and share their experiences, helping to understand how their actions affect other people, themselves, and the environment [6].

Bees in Environmental Education: Native Biodiversity in the Approximation to Nature

Since the book Silent Spring [36] was first published in 1962, the reduction of insect species in nature has been indicated as a critical consequence of anthropic actions on the environment. More than half a century later, this finding demonstrates that insects are really diminishing at alarming rates all over the world [25].

However, despite the huge variety of insect species, there is little knowledge on their biodiversity and difficulty identifying them [37, 38], and we do not even understand the most basic elements of their dynamic and distribution [25].

> Understanding insect distribution is key to evolutionary studies of origin and diversification, as well as ecological or conservation-oriented studies of how specific groups will respond to threats such as climate change or other human-induced phenomena. [39].

By studying bees, we establish a benchmark for the study of insects, as the diversity of wild bees has been diminishing in the same way for many years [39], compromising both the structure of plant-pollinator interaction networks, the balance of ecosystems, and the maintenance of plantations and the remains of native vegetation [40]. Besides being animals that are well referenced in environmental education and in green politics for participating in the conservation of nature [41], bees have various species that have adapted to the urban environment because of the disappearance of their primary habitat and a reduction in food sources [42]. For the more generalist species in search of food and refuge, urban areas have become an option, both for certain bees and for various other insect species [41].

However, in studies on the global distribution of bees, [39] present the richness of these insects (Fig. 13.1a), which, when compared to population projections in urban areas for 2050 [43] (Fig. 13.1b), and studies on urban bees in various regions of the planet, there is a negative correlation between the richness of bee species and the degree of urbanization [42].

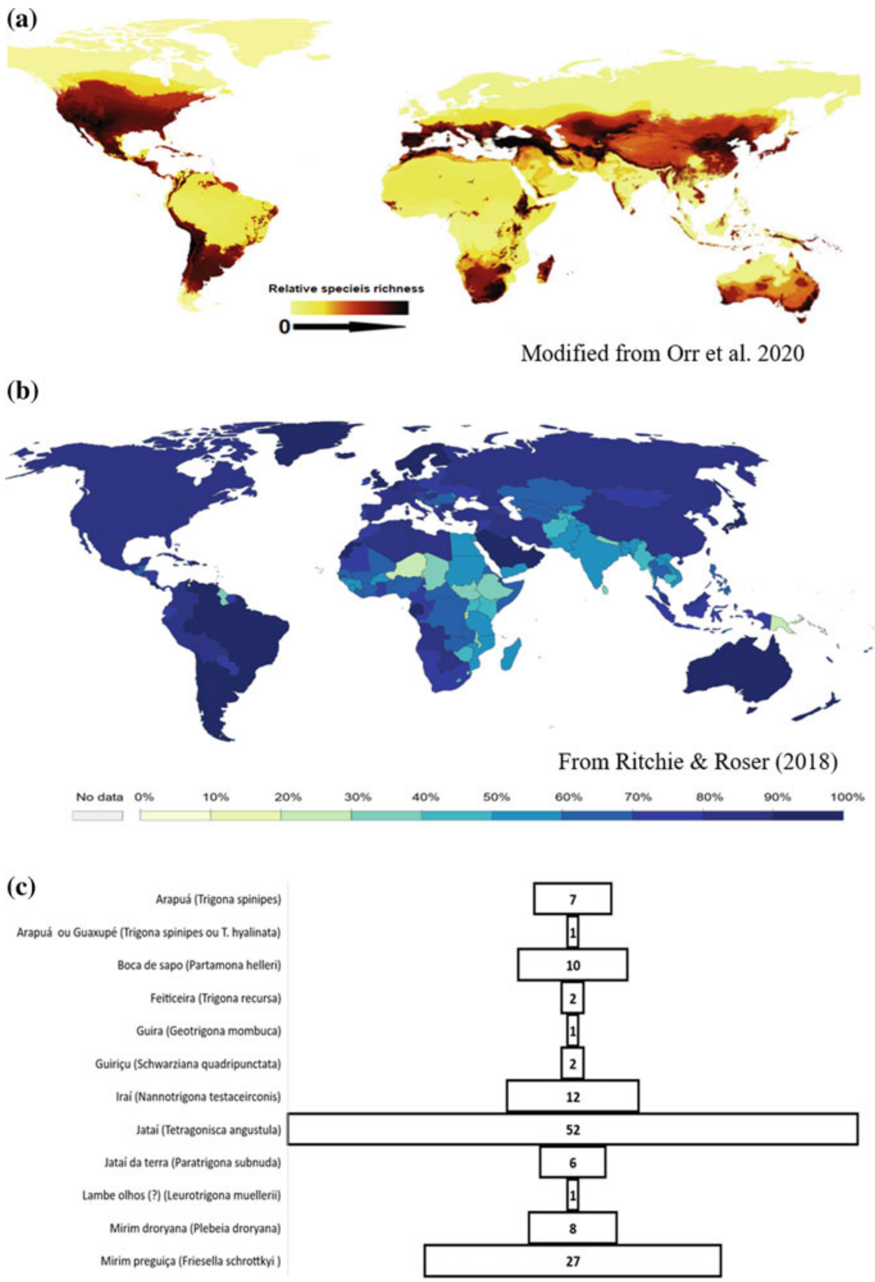

Fig. 13.1 Richness of bees' species and the urban environment. **a** Projections of bees' species richness on the world, modified from [39]; **b** Share of the population living in urban areas, with UN urbanization projection to 2050. From [43]; **c** Number of nests of stingless bees found in APA do Carmo by our study. In parenthesis, scientific name [(?) indicates that proper identification remains uncertain]

Despite this finding, in the context of urban areas, bees are insects that can be used in environmental education. According to [42] (p. 1), the ecology of urban bees is a field that has grown and broadened the knowledge on the dynamic of bee communities, enabling promotion of the conservation of these species. Even with the expansion of urban areas, the conservation of bee species can be part of environmental education programs based on studies of natural processes, when promoting green spaces in the urban design that enable the adaptation of other species [42].

In this context, the ecology of urban bees as an environmental education activity strategy should also involve the ecology of the landscape regarding the use and occupation of natural spaces as strategies that enable the improvement of urban bee habitats.

Despite being constantly cited in examples of environmental education, bees are not properly known by the public, except for the *Apis melífera* species. This is the Africanized bee that has a strong economic appeal for both its products, like honey, wax, and pollen, and the consequences of its decline for the pollination of crops. However, this is one among 20 thousand species of bee existing in the world, which, despite being unknown to the public, are responsible for most of the pollination of plants with flowers, both wild and cultivated [44].

As an activity of environmental education, we begin by discussing the global distribution of bees. In Brazil, the diversity of bee species is little known by the population, although of the nine bee families, six occur in the country. Thus, in any location in the world, the native species should be recognized and observed both locally and globally.

Despite popular thought immediately associating bees with hives, 85% of bee species in the world have solitary behavior, with varying degrees of socialization. Only some groups of the Apidae family have proper colonies, and among these, only those from the Apini and Meliponini groups have truly social behavior, with the existence of a dominant caste (the queen) and the division of work with an overlap of generations [45].

Among the bees of the Apini family, the *Apis melífera* species and its various subspecies stand out, given its economic importance. The second group of the Apini family, the Meliponini tribe, consists of bees known as stingless bees, which despite presenting a vestigial stinger, it is not used as a defense mechanism, hence their name. Stingless bees have around 500 species worldwide, distributed in tropical regions around the globe. Brazil has 92% of its territory in the tropical strip, and around 350 species of stingless bees, of which, most are only known by their scientific name. Of these, around 50 are known to beekeepers and breeders and some are bred in meliponaries.

Stingless bees use hollows for the construction of their nests, which can be both natural hollows (in trees, soil, abandoned ant or termite nests etc.) or artificial hollows (holes in walls or fences, posts, lighting boxes, bait hives made in plastic bottles and Styrofoam boxes, among others). There are species with more generalist behavior, capable of adapting to the urban environment, being relatively common in parks and woody areas of urban centers, these being *Trigona spinipes*, *Tetragonisca angustula*, and *Scaptotrigona subnuda*, among others [46]. In general, they are relatively small bees capable of using either a large variety of cavities or of constructing exposed nests, as in the case of *Trigona spinipes*. Some do not adapt naturally to the urban environment but survive in urban meliponaries when there is an abundance of floral resources or the provision of artificial food, as in the case of *Melipona quadrifasciata*. Most species, however, depend on specific conditions to maintain a genetically viable population, their breeding and management being unknown or practically impossible [47]. Larger bees, which need the hollows of large trees for nidification, such as various species of the *Melipona* genus, are the first to suffer the effects of deforestation through economic interest in the wood of such trees. In turn, species which nest in soil can construct their nests at depths of several meters, impeding their management.

Stingless bees have been increasingly used in environmental education activities due to being easily managed. Their breeding and the use of their products is widespread and specialized in countries like Australia and Mexico, while in Brazil, management and exploitation were widely practiced by native Indians prior to colonization, to the extent that most of the popular names attributed to the species are derived from the Tupi-Guarani language.

After colonization and the introduction of European subspecies by the Jesuits, as well as the growing decimation of indigenous populations, the knowledge on stingless bees was being forgotten, having survived only through rural traditions and traditional populations.

Interest in these bees began growing again in the second half of the twentieth century, especially as a result of the work of researchers like Dr. Paulo Nogueira-Neto e.g. [48], among other factors. At the end of the twentieth century and in the first decade of the twenty-first century, the breeding of stingless bees saw an increase in interest from the public, and Brazil observed an increase in the number of breeders, both of commercial interest and recreative interest, but also with a substantial interest in conservation and environmental education.

The educative potential of stingless bees goes beyond their characteristics and behavior [49]. As they are bees of easy management and are relatively inoffensive, their colonies can be maintained in schools and parks and used in educative activities, bringing approximation to natural biodiversity as a theme to generate teaching activities.

The activities described in this chapter involve the Programa Espaço Ciência Cultura e Educação (ECCE) (Education and Culture Science Space Program) of the Escola de Artes, Ciências e Humanidades (EACH) (School of Arts, Sciences, and Humanities) of the Universidade de São Paulo, and the actions of the Projeto Abelhas & Sociedade (Bees and Society Project) using stingless bees as a theme to generate activities aimed at teaching sciences and environmental education, both in formal and non-formal education.

In the project, the Programa Abelhas Nativas (Native Bees Program) stands out, developed in partnership with the Fundação Florestal de São Paulo (São Paulo Forestry Foundation) and the APA do Carmo (Management council of the springs environmental protection area), with the involvement of local schools and communities. The program contributes to the development of citizenship through approximation of the public with biodiversity, in line with the SDGs of Agenda 2030.

Interpretative Trail and Meliponary in Urban Parks and Conservation Units

In the largest city in Latin America, São Paulo (SP), Brazil, with a population of 12.33 million inhabitants distributed across 1,521 km^2, the few green areas fall into two distinct categories. These are recreational urban green areas such as parks and squares, and urban conservation units (CUs), which are hot spots of Atlantic Forest, an important Brazilian biome. The conservation units conform to Brazilian legislation for environmental protection and conservation and the treaty of the Convention on Biological Diversity (CBD), one of the main environmental agreements adopted during the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992.

On the Abelhas Nativas program, we use stingless bee species native to Brazil, with two focuses: formal and non-formal environmental education; and urban agriculture in districts of the western region of the city, where the population has low income and/or low employability. The program thus involves objectives from Agenda 2030, as, in addition to the conservationist appeal of its environmental education activities, it strives for Quality Education (SDG 4), promotes actions for the eradication of poverty (No Poverty) and for sustainable agriculture (Zero Hunger) (SDG 1 and SDG 2), incorporating elements for the establishment of Sustainable Cities and Communities (SDG 11), care with Life on Land (SDG 15), and the search for partnerships to implement local actions (Partnerships for the Goals) (SDG 17)).

The search for bee nests in trees and holes on trails, in addition to walls and fences, was carried out in an urban park and a CU. More than 129 nests of stingless bees from 12 different species (two pending confirmation) were located. The nests were geo-referenced and are part of the interpretative trails (Fig. 13.1c).

The trails are routes on which visitors have contact with the universe of stingless bees through the observation of their habits outside of a controlled environment and in an urban context. Some of the nests are identified with explanatory signs enabling the participants to observe and learn about bees. Others, however, remain only geo-referenced, being presented to visitors during monitored visits, especially those involving groups of students from visiting schools.

The itinerary of the trails includes observation of the places where the nests are established, instigating the visitors to locate their entrances, given that most of the entrances are relatively cryptic, while others are more conspicuous and with a large flow of worker bees going in and out of the nests. In addition to enabling the observation of different types of nests, the trails also enable discussion on the different behaviors found among stingless bees, and, during talking circles, the establishment of the importance of bees, the environmental services they provide, and the relationship between environmental impacts and the decline in their populations.

Parallel to the development of the trails, construction of the meliponaries was carried out inside the area of the parks, enabling the presentation of economic aspects associated with the bees. In the urban park, the meliponary is used to conduct talking circles on the observations carried out on the interpretative trails, to complement what was not seen or perceived.

In addition to the trails offered with a focus on formal environmental education in the urban parks, the non-formal component of environmental education is carried out in the conservation unit by offering beekeeping courses to the local population (Fig. 13.2b, h, i).

Both approaches achieve the objective of society understanding the importance of insects in the green fragments of urban areas and are involved in the protection and conservation of the biodiversity in these spaces, regardless of the species to be preserved.

Beekeeping enables the rational breeding of stingless bees in limited spaces, so that sustainable exploitation of their products such as honey, pollen, and wax is possible. By offering training in beekeeping to the local population as a strategy of non-formal environmental education, we enable not only the promotion of knowledge on stingless bees to the population in general, but we also contribute to the generation of income for the community through a sustainable activity. By training beekeepers from the community surrounding an urban conservation unit we approximate the local population to its natural heritage, which is often neglected.

Upon discovering the ecological and economic importance of stingless bees, in the talking circles we observe a previously not perceived valuation among the participants of the course. The courses aim to contribute not only to the conservation of one of the last remains of native forest in the city of São Paulo, but also to that of different species of insect, which, in general, society does not have moral considerability for regarding protection and preservation.

Educative Meliponary on the Campus of the Escola de Artes Ciências e Humanidades, Universidade de São Paulo, SP, Brazil

The western campus of the Universidade de São Paulo (São Paulo University) (São Paulo, SP, Brazil) is situated on a piece of land adjacent to the Tietê River floodplain in the surrounding area of the Parque Ecológico do Tietê—PET (Tietê Ecological Park). The PET is a linear park that is part of a mosaic of other similar areas, which are remains of urban projects of environmental sanitation in the city. The urban scenario where the campus is located is divided by an urban railway line and is

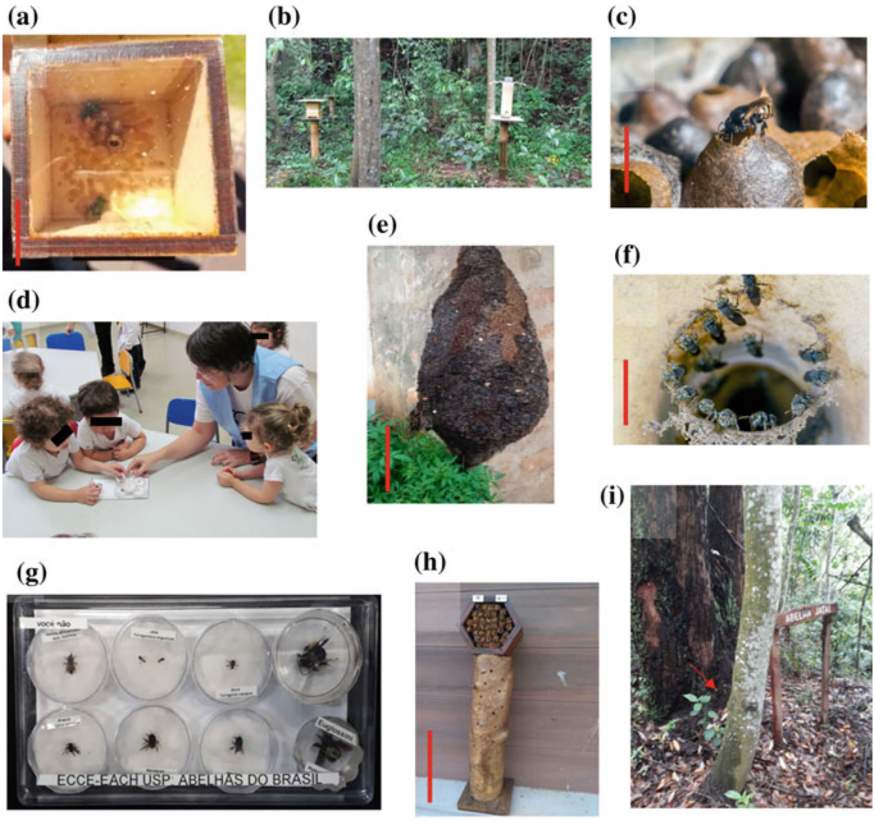

Fig. 13.2 *Bees as a goal for environmental education.* **a** artificial nest occupied by a solitary orchid bee (*Euglossa* sp.) [scale bar = 1 cm]; **b** A didactic meliponary installed in the Municipal Natural Park Fazenda do Carmo for interpretive trails in environmental education; **c** A stingless bee worker over a honey pot inside its nest (*Melipona quadrifasciata*, photo by Andre Matos, scale bar = 1 cm); **d** Scientific literacy about bees in a preschool (age 3–4 year old) applying didactic collection of bees; **e** Example of nest of stingless bee in an urban environment (*Trigona hyalinata* nest over a concrete wall, scale bar = 10 cm); **f** Example of entrance of a stingless bee nest commonly found in cities (*Nannotrigona testaceirconis*, photo by Andre Matos, scale bar = 0,5 cm); **g** Didactic collection of Brazilian bees, highlighting the exotic species *Apis mellifera*; **h** Artificial nest for solitary bees installed at Municipal Natural Park Fazenda do Carmo for environmental trails activities, scale bar = 15 cm; **i** Interpretive trails in APA do Carmo with nest of stingless bee (arrow) (Tetragonisca angustula) in a tree

heavily urbanized with one of the highest demographic densities in the city of São Paulo.

The territory has little or no forestation, but in the campus area a forested strip has been undergoing reforestation as part of the environmental compensation action of government ventures. As the only large university on the land, the campus receives many visits from the region's schools, for both recreational and educational activities.

The didactic-scientific meliponary was installed for research and environmental education purposes in an area of the campus close to the vegetation strip. The meliponary has colonies of four native species of stingless bees, three of which are in rational nesting boxes, and one is in a trunk recovered from a fallen tree. There are also perforated wooden boxes available for the nidification of solitary bees.

On the school visits we conduct a talking circle with the children and teenagers before entering the meliponary, identifying the student's preconceptions about bees, and the degree of aversion regarding the theme of insects. During the visits, certain questions are asked, such as, "what comes to mind when we say the word bee?" In general, the responses involve a set of words commonly associated with bees, such as hive, honey, and propolis. However, factors associated with the society-insects relationship are also reported, such as, stings (some report being allergic), and fear (they associate bees with insects) etc.

From this initial approach, the history of the introduction of the Africanized bee into Brazil and its consequences are reported, and we go on to talk about the environmental impacts on bees. On this point, a certain astonishment can generally be observed on the part of the students upon ascertaining that this is the case, and, as such, anthropic actions that accelerate these impacts are presented and discussed, including concepts of landscape fragmentation, deforestation, pesticide use, and the introduction of exotic species into the natural environment. In addition, we also discuss the idea of insect species diversity and the habits of bees to then proceed with the visitation.

During the visit to the didactic-scientific meliponary, the students can observe the different entrance structures of the nests of the stingless bees, as well as the inside of some of them. During observation, we talk about the biology of stingless bees, the structure of their nests, and their reproduction, returning to the topic of environmental impacts. When solitary bee nidification is available, the nest is also observed.

The presentation of concepts during the talking circle enables a participative dynamic and greater involvement of the students in the theme, as it enables the establishment of a correlation with other insects, overcoming the typical aversion of the students.

Bees and Insects in Resin: Observation and Comparison between Insect Species

This activity is both part of the visit to the meliponary and an itinerant activity when we carry out visits to schools. The presentation of the collection in resin covers other groups of insects and other arthropods, besides introducing the theme of Entomology to the students. The specimens are the product of collections in different regions, and donations by researchers etc., always keeping information on the origin of each species used (Fig. 13.2g).

In the collection of bees in resin, there are specimens of workers from different species of stingless bees, in addition to a *Melipona quadrifasciata* queen and examples of solitary bees and the introduced species, *Apis melífera*, to promote debate on invasive species and the impacts on native species.

The process of embedding in resin consists of mounting and drying the specimens (bees and other insects), with their subsequent immersion in transparent polyester resin. After the resin dries, the blocks with the specimens are sanded down with sandpaper of decreasing grades and polished with car wax. The advantage of the technique is that it permits the conservation of the specimens, and, at the same time, enables them to be freely handled by the students, as if they were alive in their hands. Thus, the animals can be observed from different angles without the risk of damaging antennae, wings, and other delicate parts, and given the transparency of the resin, their observation is also possible under a stereoscopic microscope or magnifying glass.

The collection and preparation of insects and other arthropods is an activity that enables an approximation to biodiversity, through the observation and handling of specimens. Therefore, thinking about reproducibility of the activity of teachers and students mounting an entomological collection at schools as an environmental education activity, we have developed an alternative method, mounting specimens in cotton, and storing them in transparent plastic cases sealed with adhesive tape. The specimens are bathed in alcohol and dried before mounting, which enables greater durability.

In the part on bees in our collection of arthropods, we present both specimens in resin blocks and specimens in acrylic cases (Fig. 13.2g). The handling of the fixed specimens awakens the curiosity of the students, enabling observation of species structures that are not normally presented in textbooks (Fig. 13.2d).

In the activity presenting individuals from different groups of bees, we use the student's curiosity as impetus for addressing themes related to environmental education, approximating the students to the national biodiversity, and, through the species used, demonstrating the importance of different types of insect species in the country, region, or locality in relation to processes of nature, and how the disappearance of these species would compromise other natural processes.

Final Considerations

Teaching focused on textbooks is not enough to connect the citizen to the world around them; it distances academic knowledge from the day-to-day life of the student. The use of technology in teaching broadens learning possibilities, but the lack of experience of the children with natural environments hinders a true connection with the world. The approximation of children and teenagers to natural environments and native biodiversity (especially that associated with the natural environment in which the child is inserted) is essential for the development of the child's sense of belonging to the world, as well as their responsibility as human beings for other forms of life and for future generations. Therefore, the observation of living colonies in rational nesting boxes and nests in natural conditions contributes to the emotional connection of the child to the environment. In the same way, the observation and handling of fixed specimens approximates the student to the reality of living beings, achieving a degree of recognition of fauna that the mere observation of illustrations in books is not capable of.

Bees are an important part of biodiversity, and the environmental services they provide are indispensable for human survival. Nevertheless, the public are unaware of their diversity, focusing only on exotic species introduced with the objective of trade in their products. However, given their great diversity and the existence of species capable of surviving in urbanized environments, native bees have great potential to provide a link between citizens and the environment.

Learning is a process that depends on the predisposition of the person that learns through the connections that a new concept anchors in the preexisting cognitive structure in the mind of the learner [50]. For this predisposition to occur, the new concept must make sense and interact with the reality of the student. Therefore, environmental education shouldn't be treated as watertight, passively transmitted, curricular content, but should be constructed critically, participatively, and in dialogue with the reality of the learners [51].

Tiriba and Proficie [6] indicate that several authors observe that children in the United Kingdom presented an absence of involvement with nature in outdoor environments [52–54

Knight [55] states that we should break the Cartesian division that the teaching of sciences places between humans and animals. In fact, we should overcome the simplistic animal/humans and nature/culture dichotomies, as such relationships begin being perceived as "nature", or what is "valued as nature" [56].

> to consider what happens if we take children outdoors to be with 'nature' and through an understanding that accounts for the complexities of culturally diverse 'childhoods'. [55].

By bringing native bees to the heart of the environmental discussion, be it in formal or non-formal education, a bridge is made between the content and the knowledge of the learners, making the learning process dynamic and meaningful. For this, however, it is indispensable that the presentation of biodiversity to the students is interactive and dynamic, as such, talking circles are a necessary part of the methodology used in the activities.

For the teacher, the pedagogical content knowledge (PCK) of the learning object should conform to both the theoretical references and the proposed objectives. When relating knowledge to daily life, the student re-elaborates consensual and non-consensual conceptions (misconceptions), achieving the learning objectives, and thereby overcoming the difficulties related to the aversion to insects.

Listening to the knowledge brought by the students and knowing how to use it to connect the students to the content and knowledge to be taught is an important role performed by the teacher, with the desire that their students achieve a new level of learning. When we talk about environmental education, the dialogue and the connection with nature are essential steps in the awakening of critical thinking, so that the student perceives that they are an integral part affecting the natural processes of the planet.

In this chapter, we have discussed the potential for the use of native bee biodiversity as a generating theme for the discussion of environmental issues involving contents that are generally not pleasant for students, such as insects. However, through the observation of fixed specimens and interaction with living colonies we established a starting point for discussions on themes like climate change, deforestation, and the sustainable use of natural resources. We hope to contribute to inspiring teachers to use the knowledge and resources available on native bee biodiversity in their countries and regions etc. to approximate their students to environmental themes, awakening their sense of connection with the planet.

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Chapter 14
A Natural Park Visitors' Knowledge, Attitudes and Behaviours About Sustainable Development

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A great challenge of today is to save the planet from further devastation that violates both the enlightened self-interest of humans and non-humans, and decreases the potential of joyful existence for all.
(Arne Naess, 1986)

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Abstract Being life on Earth threatened by many anthropogenic behaviours, the sustainable development (SD) goals claimed in the 2030 Agenda need to be achieved urgently. From climate changes to pandemics, loss of biodiversity, plastic in the oceans or the increasing exploitation of natural resources, there are many issues endangering the life on our planet. Science communication activities, like those developed in natural parks, allow citizens to be engaged in environmental education and disseminate sustainable development (SD) goals. The growth of scientific literacy is no doubt the first social attempt to alert people for the need of changing attitudes and to adopt pro-environmental behaviours. But before expecting citizens to use public transportation, change consumption habits or reduce the amount of waste, as examples of pro-environmental behaviours needed for a sustainable planet, it is necessary to diagnose citizens' perceptions about sustainable development. Within this framework, the present article aims to evaluate a natural park visitors' knowledge, attitudes and behaviours about sustainable development. The visitors (n = 134) of the natural park localized in the north of Portugal, voluntary answered a scale about knowledge, attitudes and behaviours concerning SD. Results showed that gender is a determinant, but no relation was found when exploring age and education. Women tend to have more pro-environmental behaviours than men, although in terms of knowledge and attitudes they are equivalent. As such, the authors do not attribute a direct relationship of an increase of pro-environmental behaviour due to environmental knowledge and attitudes. Knowing these determinants can contribute to enrich environmental education activities in science communication settings expecting an increase of pro-environmental citizens' behaviours for SD.

Keywords Environmental education · Citizenship · Scale · Science communication · Sustainability · Survey · Environmental attitudes · Environmental behaviours · Scientific literacy

Introduction

The 2030 Agenda for Sustainable Development (SD) objectives that were adopted in September 2015 covered several subjects. As a holistic concept, involving social, economic and environmental pillars, SD can be defined as economic development that is socially inclusive and environmentally sustainable [1]. Due to the impact of human behaviour on our planet, the Earth sub-systems and its dynamics has become endangered to the extent that the sustainability of life may one day become infeasible [2]. As humankind's impact on the environment is greater than ever before, environmental issues have become more important [3] and individual behaviours are widely appreciated [4]. Citizens need to be well informed to be able to cope with the new challenges such as climate change, plastic in the oceans, pandemic, exploration of natural resources and natural hazards. Pro-environmental behaviours and attitudes, as well as social and economic new ways of thinking and acting are required to achieve SD. By Pro-environmental behaviour (PEB) we consider those undertaken by a single individual to reduce one's negative environmental impact [5]. Citizens with PEB give a massive contribution to promote SD on Earth, but literature shows that although having knowledge and changing of attitudes, citizens tend not to act in a pro-environmental way. Nonetheless, as referred by Kollmuss and Agyeman [5], Non-government Organizations still base their communication campaigns and strategies claiming that more knowledge will lead to more apprised behavior. According to Blankenberg and Alhusen [3], PEB is determined by an interplay of socio-economic (for example, age, gender, education, household structure and income) and psychological (for example, beliefs, attitudes, awareness, norms, values, habits) determinants, as well as individual, social and institutional dimensions. These factors, which differ in their intensity in PEB, are well studied and documented in literature. As such, diverse authors refer that women are more willing to change behaviours than men, probably because they are more cooperative with nature, leading to a stronger concern for the environment [6]. People with more education seem to have more concerns with the environment, but a longer education does not necessarily mean increased PEB [3, 7].

Natural Parks are often the place for families' visits at weekends, or school excursions during the week. They can also be seen as a green tourism place (or as sometimes mentioned in literature, environmentally conscious tourism sets), where social pro-environmental behaviours can be experimented by all citizens. A study made by Koo and Kim [8] among nature-based tourists, revealed a positive correlation between individual values and motivations and positive effects on PEB. Within this theoretical background, it is expected that the development of quality activities in natural parks, and other science communication centres where humans can connect directly with nature, may increase citizens PEB. Studies have shown that mass media can positively contribute to the public's pro-environmental behaviours, however, others have evidenced the limited influence of traditional science communication approaches in promoting those same behaviours [9]. Therefore, some scholars argue that science communicators might have a bigger impact and better aid environmental scientists to change environmental attitudes and behaviours by acknowledging the involvement of values and addressing well-known polarised issues in environmental topics in their science communication activities instead of avoiding them [7, 9, 10]. As such, the increase of attractive and engaging activities promoted in science communication activities, like natural parks or museums, may compromise citizens in PEB giving an important contribution to promote a real change in behaviours towards a SD.

The research presented here had two main objectives. First, to do a follow-up study to analyse the fidelity and validity of a scale to evaluate knowledge, attitudes and behaviours for SD in Portuguese visitor of a natural park. Second to analyse the results of the scale applied to visitors of a natural park to gather data related to determinants of pro-environmental behaviours, namely gender, education and age. Authors expect that the knowledge of those determinants can potentiate the development of science communication activities in natural parks capable of motivating the visitors to adopt friendly and intentional behaviours for SD.

Methodology

A survey was applied to the visitors of a natural park in the north of Portugal. The intentional sample was chosen based on the assumption that people interested in natural parks have some concerns with environment and SD. As such the study was based on the acceptance that visitors of natural parks could give an idea of the citizens' perceptions about sustainable development. The instrument applied was a scale adapted and validated by Borges [11] to be applied to the Portuguese population.

Sample

The scale to evaluates knowledge, attitudes and behaviours concerning SD was applied during 3 months and to all visitors (n = 134) to the natural park over the age of 18 years old. The average age was 38 and the oldest person was 75 years old. Characteristics of the sample are shown in Table 14.1.

The participants voluntarily agreed to collaborate in this study. Visitors were approached in the beginning of their tour in the park and invited to fill in the scale and leave it at the reception at the end of the visit.

The average time to fill the scale was 3 min, although the instrument was not timed. Only 33 visitors (24.6%) visit the park as a family group and the majority of them 64 (47.8%) are regular visitors, having been there more than five times.

Instrument

The scale was validated to the Portuguese population by Borges [11] and was elaborated based on a translated version from the original questionnaire of Michalos and collaborators [12]. The dimensional structure of the scale was assessed by resorting to factor analysis and items that scored higher than 0,30 were accepted in one of the three dimensions. The highest value of all was considered for those items that were inserted for more than one factor. The scale validated by Borges [11] maintained

Table 14.1 Characterization of the sample

Gender *f* (%)	Age *f* (%)		Academic qualifications *f* (%)	
Female 77 (57.5%)	18–36 37–57 58–75	32 (41.6%) 38 (49.3%) 7 (9.1%)	Middle or secondary school Graduated Post-Graduated (master or Ph.D.)	28 (36.4%) 35 (45.5%) 14 (18.1%)
Male 57 (42.5%)	18–36 37–57 58–75	29 (50.9%) 23 (40.4%) 5 (8.7%)	Middle or secondary school Graduated Post-Graduated (master or Ph.D.)	18 (31.6%) 26 (45.6%) 13 (22.8%)

the three-dimensional structure, as previously determined by Michalos and collaborators [12]. Results shows that factors explain 34,1% of total variance—factor 1 (Knowledge), factor 2 (Behaviours), and factor 3 (Attitudes).

Borges (2019) final scale had 33 items divided into three dimensions (Knowledge—11 items, Attitudes—10 items and Behaviours—12 items). Table 14.2 shows the items of each sub-scale.

Good values of internal consistency were obtained by Borges [11] after applying the scale to a sample of 168 Portuguese high school students. The internal consistency of the three dimensions was measured through the calculation of the alpha of Cronbach: Knowledge (α Cronbach = 0.84), attitudes (α Cronbach = 0.82) and behaviour (α Cronbach = 0.83). The 33 items can be answered in a 5 points Likert scale, going from totally disagree to totally agree.

Results and Discussion

The presentation of the results of the scale is twofold. First the researchers made a follow-up study to analyse the validity and reliability of the scale when applied to citizens. Secondly, a statistically analysis of the answers was done to verify the average of the participants' responses in the three dimensions and to compare answers between citizens.

Follow-Up Study of the Scale

The follow-up study analysed internal consistency and ensured reliability, by resorting to Cronbach's alpha coefficient of the items of the three dimensions. Results obtained showed a very good reliability confirming the results of the study of Borges [11]. The values per factor are showed in Table 14.3.

High α coefficients were found to all the dimensions. Note that a value for alpha either higher than or equal to 0.80, indicates that the items are strongly correlated [13].

Following the validation process, 33 items were selected for the statistical procedures.

Statistically Analysis

The average of the visitors' answers to the three dimensions of the scale was very high regarding Attitudes (M = 46.1; s.d. = 4.24) and Knowledge (M = 49.8; s.d. = 4.68) related to sustainable development, but not so high when asked about Behaviours (M = 38.4; s.d. = 9.14). Table 14.3 presents the average scores achieved in each

Table 14.2 Scale items in each dimension (adapted from Borges [11] (p. 25))

Knowledge (11 items)	Attitudes (10 items)	Behaviours (12 items)
√ Ensuring a long and healthy life for all contributes to sustainable development	√ We need stricter laws and regulations to protect the environment	√ I have taken a course in which sustainable development was discussed
√ Sustainable development requires quality education for all	√ Governments should encourage greater use of fuel-efficient vehicles	√ I have already participated in activities related to environmental sustainability
√ Sustainable development emphasises respect for human rights	√ Adopting sustainable development as a national priority is key to maintaining Portugal's status as one of the most liveable countries in the world	√ I have been thinking about what it means to live in a sustainable manner
√ Sustainable development entails a reflection on the meaning of quality of life	√ The teaching of sustainability principles should be integrated into the curriculum in all disciplines and at all levels of schooling	√ I have already looked up information about the new sustainable development goals of the United Nations
√ Poverty alleviation is an important topic in education for sustainable development	√ Citizenship education is an important component of education for sustainable development. Every girl or boy should receive education that teaches the knowledge, perspectives, values, issues and skills for sustainable living in a community	√ I often look for signs of ecosystem deterioration
√ Helping people out of poverty is an essential condition for Portugal to become more sustainable	√ Overuse of our natural resources is a serious threat for the health and welfare of future generations	√ I talk to others about how to help people living in poverty
√ Building appropriate infrastructures contributes to sustainable development	√ The present generation should ensure that the next generation inherits a community at least as healthy, diverse and productive as it is today	√ I have already looked up information about the environment or sustainability of the university on the respective website
√ Sustainable development emphasises gender equality	√ Sustainable development will not be possible until wealthier nations stop exploiting the labour and natural resources of poorer countries	√ I usually look at problems from different angles
√ Food safety is one aim of sustainable development	√ Manufacturers should discourage the use of disposables	√ I walk or bike to places instead of going by car
√ Estimating the monetary value of the service our ecosystems provide (such as: neutralising air pollutants) is important for sustainable development	√ Taxes on polluters should be increased to pay for damage to communities and the environment	√ I volunteer to work with local charities
√ Sustainable development emphasises international cooperation		√ I try to avoid purchasing goods from companies with poor track records on corporate social responsibility
		√ The household tasks in my home are equally shared among family members regardless of gender

Table 14.3 Cronbach's alpha reliability coefficient for each factor and descriptive statistics

	α coefficient	Minimum	Maximum	Mean	Standard deviation
Knowledge (n = 134)	0.84	13	55	49.8	4.68
Attitudes (n = 134)	0.84	28	50	46.1	4.24
Behaviours (n = 134)	0.86	18	60	38.4	9.14

dimension as well as the minimum and maximum values per dimension. These results indicate that behaviours are more difficult to accomplish than a change in attitudes or acquiring knowledge about sustainable development. To better analyse these results, Pearson correlation coefficient between the three dimensions of the scale was analysed. Although the correlation between the three dimensions were all significant ($p < 0.01$) they are weaker between Knowledge and Behaviours ($r = 0.231$, $p < 0.01$) and Attitudes and Behaviours ($r = 0.271$, $p < 0.01$), being higher between Attitudes and Knowledge ($r = 0.561$, $p < 0.01$). These results are similar to the findings in other works, where authors claim that pro-environmental behaviours are difficult to achieve and depend on numerous factors [3]. As stated by Kollmuss and Agyeman [5], even when we might be willing to change our behaviour, if we do not persist enough in practicing new habits old routines will persist and we still do not change it—we are caught in our previous behaviours. The same authors do not attribute a straight relationship to environmental knowledge and pro-environmental behaviour, but also to an emotional involvement that they called '*pro-environmental consciousness*' [5]. They refer to this complex as embedded in broader personal values and related to other personal factors (for example, cultural factors) [5].

Nevertheless, an independent sample T test analysis was done to verify if the average of the answer to each of the scale dimensions between gender was different. Results showed that there is no different in answers regarding Knowledge ($t_{(132)} = 1.335$; $p = 0.184$), but significant differences were found in Attitudes ($t_{(132)} = 2.396$; $p = 0.018$) and Behaviours ($t_{(132)} = 2.342$; $p = 0.021$). Women are the ones that have higher average in both, attitudes and behaviours. This result showed that women have more attitudes and pro-environmental behaviours towards sustainable development. The higher average obtained by women was on question "I have been thinking about what it means to live in a sustainable manner" ($M = 4.05$; $s.d = 0.872$).

Influence of the variable Academic Qualifications, groups Middle and Secondary School (n = 46; 34.3%), First Graduation (n = 61; 45.5%) and Post-Graduated (master and Ph.D.) (n = 27; 20.2%), in the scale dimensions under analysis was determined using an analysis of variance (Table 14.4).

Results highlight the inexistence of any statistically differences between students concerning the following dimensions: Knowledge ($p = 0.638$); Attitudes ($p = 0.870$); and Behaviours ($p = 0.987$), which means that the independent variable (academic qualification) is not very influential.

Table 14.4 ANOVA between groups of academic qualifications and scale dimensions

	Source of variance	Sum of squares	Mean	df	F	p
Knowledge	Between groups Within groups	8.260 62.046	0.46 0.54	18 115	0.850	0.638
Attitudes	Between groups Within groups	5.419 64.887	0.34 0.56	16 117	0.611	0.870
Behaviours	Between groups Within groups	12.164 58.142	0.32 0.61	38 95	0.523	0.987

Table 14.5 ANOVA between groups of age and scale dimensions

	Source of variance	Sum of squares	Mean	df	F	p
Knowledge	Between groups Within groups	5.928 49.155	0.33 0.43	18 115	0.770	0.730
Attitudes	Between groups Within groups	5.185 49.897	0.32 0.43	16 117	0.760	0.727
Behaviours	Between groups Within groups	11.510 43.572	0.30 0.46	38 95	0.600	0.924

The influence of the variable age, groups Range 18–36 ($n = 61$; 45.5%), Range 37–57 ($n = 61$; 45.5%) and Range 58–75 ($n = 12$; 9.7%), considering the scale dimensions under study, was evaluated by resorting to an analysis of variance (Table 14.5).

Results highlight the inexistence of any significant statistical differences between students concerning knowledge ($p = 0.730$); attitudes ($p = 0.727$); and behaviours ($p = 0.924$), meaning that the independent variable (age) is not very influential.

Both results obtained between Education and Gender and the scale dimensions, are aligned with previous studies, as stated in the introduction section.

Conclusion

The follow up study of the scale corroborated the values published by Borges [11] and confirmed that validity and reliably of the scale are trustful and can be used in further studies with the Portuguese population.

The study based on the mentioned scale showed that despite the knowledge and the attitudes regarding SD of the citizens (visitors of a natural park), they tend to have more difficulty in changing behaviours. This means that pro-environmental behaviours are difficult to achieve even when the attitudes are supported in a substantially well informed and understood knowledge of the need for a SD. Although the sample of the study was not random, not allowing the generalization of the results, it is possible to refer that there is a tendency for citizens to be well informed but also to be caught in routine habits and being reluctant to replace behaviour. Results showed that pro-environmental behaviours are more developed by women. As such they could be the ones to be more active in social innovations for SD, but this last assumption needs studies to be confirmed, being subject to debate and gathering evidences. On the other hand, results showed that age has no interference with pro-environmental behaviours nor influence the knowledge or attitudes toward SD. As such we cannot assume that older people engage less often with SD issues. Education (academic qualification) also showed no interference with pro-environmental behaviours, attitudes or knowledge related to SD. Despite the fact that educated people are more aware and more concerned with social welfare, the study did not prove that Education increases PEB.

These evidences may contribute to the development of new and enriched environmental education activities in science communication settings (like, for example, natural parks) to stimulate citizens to have more PEB towards SD.

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Chapter 15
Start Park Project: Co-designing Green-Blue Infrastructures to Build Resilient Communities to Climate Change

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Abstract Nature-based solutions (NBS) are becoming a relevant approach to design urban green areas as green-blue infrastructures (GBIs) capable of delivering multiple ecosystem services. Thanks to the key aspect of providing multiple benefits, GBIs are one of the main solutions proposed for Climate Change (CC) adaptation and mitigation. At the same time, collaborative and design-based methodologies are raising attention on the design of GBI, allowing to design public spaces with a bottom-up approach. Indeed, the traditional top-down approach often adopted by municipalities in designing green parks and areas has proven to be insufficient for the design of public spaces. Moreover, co-design of GBI can also be an opportunity to raise sustainable development awareness in the population. This chapter wants to share the experience of the Start Park project, a methodology developed for the co-design of GBI for CC adaptation with citizens. Specifically, the chapter highlights the educational value of a Start Park process, with particular attention on the social impact obtained in the two experiences in the municipalities of Prato and Lucca.

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Introduction

One of the key peculiarities of modern society is that societal stakeholders are increasingly engaged in dealing with challenges that go towards common objectives and duties [1]. In this context, citizen and community engagement (CE) techniques have been recognized as fundamental leverage to involve and empower local communities in challenges, especially those related to the aspect of sustainability linked to climate change (CC) [2]. Engaging all urban actors around practical problem-solving is necessary, as it enhances the efficacy of climate change adaptation strategies [3]. As a consequence, collaborative design or co-design—i.e. engaging users and other concerned stakeholders in the creative process of design [4]—becomes essential when facing wicked problems [5] such as CC adaptation strategies.

CC issues are extremely complex if considered in the urban context, since spaces to implement solutions for CC adaptation and mitigation are very limited. Therefore, green-blue infrastructure (GBI), which can be defined as green and blue areas capable of providing multiple benefits to the citizens and the society, offer a crucial advantage, as they can be designed so that the original use of the area is maintained; parks and public spaces can become elements against CC, while remaining usable by citizens. Moreover, GBIs are considered suitable solutions to CC adaptation by exploiting their multiple ecosystem services (ES) [6]—i.e. socio-cultural and economic benefits arising from nature-based solutions. However, the CC adaptation challenges cannot be addressed with GBIs alone: citizens are a fundamental part of the process, as they are potential adopters of environmentally-aware behaviours. The Start Park concept goes in this direction: parks are intended as 'common goods' for citizenship and urban life, they should not only be the first outposts of CC urban adaptation, but a place for social aggregation and personal and collective well-being. Therefore, the Start Park experience is in line with the recent increase in the consideration for community engagement [7] and co-designing (for instance, the UNALAB tools for creation of NBS—https://unalab.enoll.org/) within the GBI implementation programme.

Start Park (SP) was funded by two European grants under the umbrella of the Designscapes project (H2020) and represents an innovative citizen-led co-design process aimed at collaboratively re-designing urban green areas with GBI by leveraging on design thinking methodologies, digital gamification and STEM-environmental studies. In particular, SP addresses a diversified set of problems and pursues several objectives: first, Start Park tries to adjust the inadequate and not up-to-date design and architecture of the urban environment, in particular urban parks, when related to the contemporary climate-related challenges and severe events. Second, it addresses citizens' unawareness about CC and the generalized lack of education on tools and methodologies to become resilient organisms. Third, SP deals with the need to redesign our urban environment exploiting nature-based solutions

(NBS) multiple ecosystem services. Fourth, it boosts experimentation and new forms of design network, composed of public–private stakeholders, able to create new socio-economical value—e.g. social value with the Start Park participatory project, economic value with its legacy, namely the opportunity to create labour out of new major infrastructural works for urban resilient transformation.

Start Park was prototyped and scaled in the municipalities of Prato and Lucca (Italy) and it involved heterogeneous end-users in different co-design contexts requiring a great usage of co-design and service design tools, together with the creation of personalized and gamified ones (e.g. Start Card game card). The goal throughout the Start Park development was, indeed, to enable participants to design a Start Park while understanding key technical and scientific aspects of GBIs with the aim of leveraging the empowerment of participants and becoming catalysts of sustainable urban innovation. Besides the ability to reach a detailed design of a park as a GBI for CC adaptation with a bottom-up approach, Start Park has an intrinsic value for education on CC issues as well as adaptation measures with GBI that this chapter wants to focus on. Firstly, an overlook of the Start Park process is given, including the presentation of the whole co-design process. Secondly, an overview of the results from the use of the co-design process in Prato and Lucca is given, particularly on the results obtained in terms of detailed design of two urban parks and GBI for CC adaptation. Finally, the chapter investigates the intrinsic educational value that a Start Park process delivers to citizens.

Start Park Process

Start Park is a spin-off project created by IRIDRA Srl and Co-design Toscana, which activates local associations—i.e. CUT in Prato, Lucca Creative Hub in Lucca-, in order to develop new *concepts* for resilient urban parks involving the local neighbourhood committee, public administrators, local school students and parents, artists and activists, stakeholders interested in green and socially engaged practices. One of the main challenges tackled by the project concerns spreading environmental awareness among European citizens through the co-design of urban green areas able to adapt to CC consequences, specifically connected to water management, that are affecting cities. With these challenges and objectives in mind, the Start Park concept was prototyped, in 2020, by co-designing a peripheral park in the Prato Municipality and its design process was scaled, during 2021, in the Lucca Municipality for the Parco Valgimigli, a green area near the historical city centre.

The Start Park process, which lasts 6–9 months and comprehends a number of technical activities to properly design a GBI, is based on a non-linear design thinking approach inspired by the double-diamond model [8, 9] and uses gamified, design-based methodologies to fulfil its objectives. A minimum of 5 participatory events divided into three types—animation, co-design and co-creation- is required to give efficacy to the process (Fig. 15.1 depicts some snapshots of the activities). In

Fig. 15.1 An overview of the Start Park activities in Lucca and Prato

particular, we refer to methodological frameworks derived from participatory design practices [10] and community engagement strategies [7] focused on GBI.

During both the Prato and Lucca processes the Start Park process was conceived as follows:

- 1st event—Launch of the project (Animation), aimed at highlighting the issues and ambitions for the park, the citizens, and the surrounding area.
- 2nd event—Co-design of the GBI (Co-design), aimed at delivering co-designed GBI concepts for the park in response to specific social challenges.
- 3rd event—Hard-to-reach target (Animation), aimed at understanding and engaging marginalized user groups through socio-cultural research methods—i.e. in-depth interviews and on-site observation.
- 4th event—GBI rapid prototyping (Co-Creation), involving specific target groups in order to build collaboratively examples of nature-based solutions while raising awareness on ecosystem services.
- 5th event—closure party and final restitution of the party (Animation), dissemination of the SP process output through offline and online events e.g. live streaming presentation via Facebook, small groups guided tours in the park.

The Start Park architecture has been conceived with an adaptable, multi-objective and incremental process of co-design. Each phase of the process can be adapted in response to specific needs and emergencies. As a matter of fact, when the covid-19 pandemic hit Italy in 2020, Start Park activities were shifted from offline in-person activities to online channels using different digital collaboration tools—e.g. Google

Jamboard, Mirò, live streaming on Start Park social media pages. Moreover, the different contexts and territorial peculiarities in which Start Park is adopted required different social research tools, design methodologies, usability and affordance strategies for effectively engaging audiences. For instance, in Prato and Lucca, *hard-to-reach target groups* were identified after an initial in-field research and observation. This allowed the Start Park team to understand the accessibility needs and format languages required for best engaging with the local target groups.

A key aspect is the multi-objective dimension of the Start Park process, which relies on different value propositions delivered while implementing a project. On one hand, SP wants to achieve educational and awareness impacts on the target groups involved. Being part of a SP project enables participants to understand both the main constraints and threats of CC, the differences occurring between adaptation and mitigation strategies, discover GBI for water management and collaborative prototyping of NBS through design thinking tools. On the other hand, SP creates value for urban policies and sustainable development relating to cities' transformation: outputs of Start Park range from pre-feasibility technical proposal of the new co-designed resilient park to the participatory process that brings out a series of citizens' needs, criticalities and opportunities related to the transformation of the area.

Finally, the incremental structure of Start Park is highlighted when replicating the process in a new urban context. The design process takes the lesson learnt from the previous user research and co-design experiences as a starting point [11]. During the practical cases in Prato and Lucca, each event was designed to progress and optimize the co-design of the GBIs for the parks as well as setting up validated social science tools to build a resilient community, mixing a number of different activities related to multidisciplinary competences and objectives—i.e. engagement, co-design, communication, design, engineering and architectural design.

Start Park employs specific tools derived from service design and social science disciplines [12]. In terms of design-thinking process, Start Park relies on the following four main phases which use different co-design tools (Table 15.1):

- **Exploration**: a site-specific exploration phase of the context and related opportunities using observation, interviews, focus group, world cafes. The insights from these activities are summarized within cultural probes, personas and stakeholders' maps; then moving on to the building of possible scenarios to open the discussion towards the problem setting phases.
- **Ideation**: co-design workshops take place to generate ideas based on the insights gathered during the exploration. To foster the ideation phase and jump to the prototyping one, design tools such as brainstorming, scenarios, user journey map and service blueprint are used mixed with mediation tools designed to facilitate the comprehension of some key technical information about GBIs and CC adaptation (e.g. Start Cards game).
- **Test and validate**: in order to collect feedback about the ideas of the previous stages, experience prototyping and service walkthrough tools are used by the co-designers. This kind of co-design practices include room for iteration and further prototyping based on the collected feedback.

Table 15.1 Service design and social sciences tools used for Start Park

	Exploration	Ideation	Test and validate	Converge
Personas	X			
Cultural probes	X			
Stakeholder map	X			
Design scenarios		X		
Start card game		X		
Co-creation workshop		X		
User journey map		X		
Service blueprint		X	X	
Experience prototyping			X	
Service walkthrough			X	
Business model canvas				X
Open space technology				X

- **Converge**: the synthesis of a single design solution for the final output of a Start Park is essential for a clear and collaborative technical study of the area. We used public voting, debates and open space technology [13] in order to collaboratively choose the best developed scenario. Delivering this pre-feasibility technical proposal to public administrators and policy makers is the last step of Start Park and represents a professional output that embeds '*voices and ideas*' from all the participants.

The Co-Design Green-blue Infrastructures of Prato and Lucca

Start Park is a reality for a peripheral neighbourhood of two European cities, the city of Prato (IT) and Lucca (IT), in which Start Park was prototyped and scaled. IRIDRA, with the support of Codesign Toscana and the local associations CUT and Lucca Creative Hub, has prototyped the Start Park concept involving the local neighbourhood committee, local primary school students and parents, artists interested in green and socially engaged practices and activists to imagine and design a Start Park in a green residual area of the Prato and Lucca cities. In Fig. 15.2 are depicted the representative outputs of a Start Park and this section describes the main outputs of the process as community-driven NBS for urban resilience.

Fig. 15.2 Start Park documental outputs in Prato

Replication Tools

The main outputs of a Start Park process, based on the two case studies in Prato and Lucca, were:

- Start Park guidelines: aim at orientating future Start Park replicators; more specifically, the Start Park guidelines describe the minimum activities needed to propose and carry out a Start Park process in other cities, with a particular attention to the description and suggestions for a successful implementation of the participatory events.
- Start Park toolkit: a number of tools (both online and offline) that can be used to co-design a Start Park, including the Start Card, a dedicated game to make every citizen a co-designer of GBI in response to CC. These tools are provided to support the guidelines to replicate Start Park. The toolkit is composed of: Co-creation tools, i.e. no. 26 street furniture schemes to aid the creation of a 3D relief map of the park, and material for the hand-made implementation of GBI (a rain garden), i.e. no. 1 instruction manual, and no. 1 video tutorial.
- Visual identity tools: to maintain and scale a common language across different Start Park replications (fonts, colour, logo, icons, gifs, slide template).
- Proposal tools: material aimed at supporting the proposal of the short replication concept of Start Park, no. 1 technical report on the Start Park methodology, no. 1 slide presentation, no. 8 disseminative videos on Start Park and CC adaptation concepts, no. 5 videos of the Giardini di Prossimità GBI co-designed concepts (Fig. 15.3).

Fig. 15.3 Explanatory render of a GBI co-designed in Prato: Phase 0: dry period, part of the wetland is dry and part is wet, the swale is dry; Phase 1: during low-intensity rain events, the swale and all the wetland is wet; Phase 2: during heavy rainfall, all the NBS elements, swale and wetland, are occupied by water at full lamination capacity; Post Phase 2: the park is lived in safety

Pre-Feasibility Technical Proposal

The Start park process ends with a pre-feasibility study of the co-designed park, including the framework of the area, the preliminary design of the GBI, the preliminary cost estimation, and technical drawings. It is worth to remark that the pre-feasibility study is the sum-up of an urban park designed with a fully bottom-up co-design approach (Fig. 15.4). The pre-feasibility study is delivered to the local municipality and it is at a basic-design level, suitable to fulfil the Italian legislation requests to proceed towards the detailed design and implementation.

More in detail, the co-designed parks of Giardini di Prossimità in Prato and Valgimigli in Lucca included rainwater harvesting schemes, with rain gardens for filtering the harvested rainwater. Subsequently, the rainwater is delivered towards small wetlands with swales. Both wetlands and swales are designed to accumulate a significant volume of rainwater during heavy rainfall, while allowing to reuse the harvested rainwater during drought periods. Recreating an open water ecosystem in urban context, the co-designed GBI is able to also fulfil the goal of biodiversity support and reduction of heat island effect. With the aim of mitigating floods, droughts and heat island, of improving water quality and supporting biodiversity, the co-designed urban parks can be seen as an example of GBI for CC adaptation.

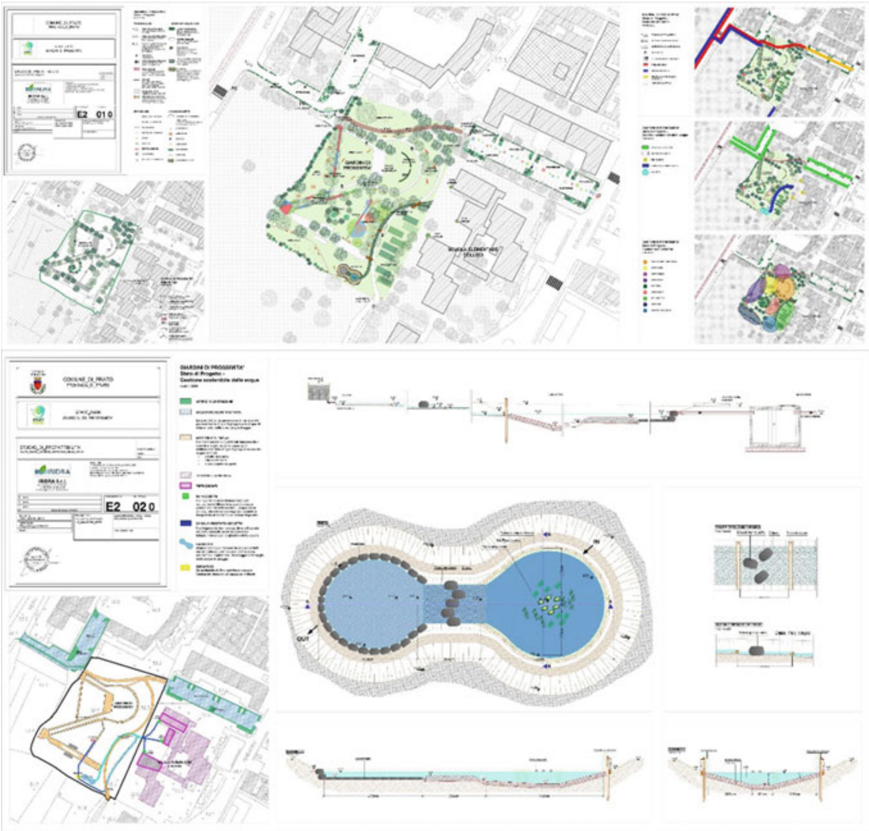

Fig. 15.4 Start Park technical outputs in Prato

Together with citizens and stakeholders, the urban parks were also co-designed in terms of furniture and social activities, in order to raise a community around the new Start Park.

Evaluating the Impact: The Start Park Factor

Thus, when dealing with a Start Park process, the two main drivers that deliver value are: firstly, the innovative process that permits to effectively reach a basic design of the GBI to be delivered to the municipality, in order to proceed in the next design and implementation phases; secondly, and most important, the building of a local and creative community resilient to CC through the co-design of the GBI through educational activities and participatory design practices.

A final focus about Start Park outputs is on the assessment and measurement of the overall impacts of its process. It represents a striking feature to give consistency and efficacy throughout the project. Thus, the team is building and delivering a multidimensional impact assessment index, the Start Park Factor, to calculate the local value creation where Start Park is adopted. In particular, the Start Park factor is able to measure impacts on different intertwining dimensions relating to social, cultural, economic and environmental value. Below, a list of proxies and indexes on which we calculate the impact of a Start Park process:

1. Socio-cultural impact

– Knowledge transmission and sustainable thinking with respect to climate change and sustainability, GBI and other resilient practices, design tools and processes (co-design, design thinking, prototyping), strengthening of both digital and remote collaboration competences;
– Facilitation of stakeholders' local networks for the implementation of SP projects and knowledge, competences and experiences exchange;
– Engagement of every public–private stakeholder's category in the training (e.g. schools, public administrations, NGOs, industry players and SMEs)

2. Socio-environmental impact

– Impact assessment and training (potential and effective) on:
  – GBI impact on climate change adaptation strategies
  – Design of sustainable and resilient services
  – Design autonomy and stakeholders' behavioral changes

3. Economic impact

– Contributions to the collection of *innovative and green and sustainable thinking* skills for the job market
– Facilitations in the creation of new stakeholders' networks for job and project development opportunities
– When dealing with the co-design and implementation services SP creates direct economic spillovers on local urban ecosystems: SP develops local economies through direct occupation for territorial players—i.e. catering services, architectural and engineering consultancies, third sector services.

The Educational Value of the SP Process

The learning experience of Start Park represents a strategic asset with the potential to address different target groups in raising awareness about urban sustainable transformation through nature-based solutions. Since its conceptualization, the Start Park founding team has made use of educational activities using accessible language and inclusive technical tools. During the opening activity of the Start Park in Prato,

Fig. 15.5 Light frontal explanation + semi-structured brainstorming

the first animation targeted children between six and ten years old, using cooperative learning methodologies [14]. Children of the neighbourhood were involved in a gamified role playing activity, called 'Kids envisioning', in order to disseminate the basic functioning of rain water cycles and its interaction with the urban dimension. The design process of the activity was:

1. Light frontal explanation and semi-structured brainstorming based on the open question "What does it happen when it rains?" (Fig. 15.5);
2. Role playing associating each player with urban natural elements—e.g. trees, shrubs, rocks. (Fig. 15.6)—and their function in the rain water cycle. Then, dropping blue balls (simulating rain drops) on an inclined plane (Fig. 15.7) each pupil acted as its element in order to direct the water flux towards its final collection point (Fig. 15.8).
3. Finally, they were challenged to interpret the water cycle through a creative practice of sketching (Fig. 15.9) by answering the checking question "How does the water go from here to there?

Another educational and disseminative activity that took place during Start Park in Prato, as a response to the covid-19 urgency to re-design activities, was the Start Park Quiz. This informative format encompassed remote educational and participatory activities launched on SP social media channels with the aim to engage the digital audience of Start Park during the covid-19 lockdown. A multiple-choice quiz was

Fig. 15.6 Urban natural elements

Fig. 15.7 Dropping rain drops

Fig. 15.8 A water containing point

Fig. 15.9 Creative sketching of the water cycle

launched every week in the Facebook group 'Start Park Community', then the Start Park team answered in a live talk on Facebook through an open discussion involving local guests and experts. The Start Park quiz regarded the following topics, for which the registered video (in Italian) is available in Start Park YouTube channel as a dissemination tool:

- Climate change impact on water management;
- Active citizens and climate change;
- Design thinking and co-design in response to climate change;
- Start Park: instruction for reuse;
- The role of architecture in designing green-blue infrastructure;
- Art and nature for awareness raising and education of future generations;
- Gamification and co-design for empowerment and climate change adaptation;
- Self-construction and material reuse for Start Park co-creation.

Further educational activities took place during the SP in Lucca; in particular, the co-creation activities for the GBIs rapid prototyping phase specifically targeted high-school students and unaccompanied minors to freely imagine a summer festival for their peers to be held in the future Start Park. In order to implement this activity, the SP team proposed an online role-playing activity through the use of a remote collaboration software. The design process of the activity was:

1. Choosing avatars and game characters, participants empathized with the park users and their needs.
2. Using image sorting, they associated characters with future activities to experience in the Start Park.
3. Through the means of future envisioning tools—e.g. cover story and storyboard—participants built design scenarios of future experiences in the park.

The results of the activity were the production of a fiction newspaper, which describes the activities of the summer festival (Fig. 15.10). As a confirmation of the

Fig. 15.10 Newspaper from the activities imagined for the summer festival in the Valgimigli Start Park. Activity done by the high-school students and unaccompanied minors in Lucca

educational value of this activity and of Start Park in general, one of the participants proposed Start Park as the subject of his thesis in a middle School in Lucca, receiving great interest from the teachers. Currently, the Start Park team is in contact with the student's teacher to propose similar activities in other schools in Lucca.

A final focus on the educational activities of Start Park is about the gamification service of the Start Park Game Card, which is an undeniable strength of the overall Start Park process. The Start Park Game Card represents the output of an internal research and design work that produced a complete set of game elements (Fig. 15.11)—i.e. no. 1 instruction manual, no. 23 GBI cards, no. 30 street furniture cards, no. 16 activities cards, no. 8 envisioning cards, and no. 1 board game framework—that provides an innovative tool to co-design GBIs in response to CC within urban parks. In particular, the GBI cards summarise all the key elements to make every citizen a designer:

- a scheme graphically explains in a clear manner the functioning of the GBI
- a short description explains the functioning of the GBI
- the key function in managing water (linear, punctual or surface interception element) is clarified by a dedicated icon
- a score in terms of construction and operational and maintenance cost is given (1, low; 2 middle; 3 high)
- a score relative to 5 CC challenges (flood, droughts, heat island, water quality, biodiversity) is given in terms of CC adaptation (1, low; 2 middle; 3 high)

This co-design game embeds future directions of the Start Park project. The Start Park team is optimizing its features, gaming aesthetics and dynamics in order to release it as a tool for different target audiences: first, for families, schools and game

Fig. 15.11 The Start Park game card to co-design GBIs in urban green areas

enthusiasts in order to provide an innovative, cooperative and serious game with the focus on sustainable urban transformations in response to climate change threats; second, for technical departments, public administrators and professional studios that looks for an ad-hoc tool to engage clients, provide consultancy and co-design with them resilient public and private green areas.

Conclusions

To sum-up, the educational impact of Start Park can be addressed under different types of lens and it became an essential feature for both user engagement and growth strategy. First of all, Start Park brings an innovative and replicable process throughout cities that has the potential to align public–private interests in developing sustainable urban solutions while bringing educational side-activities to citizenship and services to a multitude of users and target groups. Second, Start Park provides accessible tools in order to update the knowledge of public–private technical departments about the nature-based paradigm and to transfer service design thinking methodologies to public bodies and civil society. Third, Start Park trains diverse segments of park users and has the potential to create networks of actors able to replicate the Start Park model throughout Europe: from the youngest to the local associations representatives, from environmental movements to informal groups of active citizenship. Fourth, Start Park gamification and design thinking tools might enhance the urban ecosystem accessibility and the ability to solve wicked problems; moreover, its cooperative learning approach can be brought to schools as part of new interdisciplinary education models.

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Chapter 16
Societal Embedding in Geoparks: A Case Study in Portugal

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Let my armies be the rocks, and the trees, and the birds in the sky.
Dr. Henry Jones
Indiana Jones and the Last Crusade

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Abstract Through the awareness of the geological heritage, a UNESCO Global Geopark provides the region's inhabitants an opportunity to develop cohesive partnerships and to enhance creative initiatives as a means to stimulate a sustainable local economy. In order to achieve it, UNESCO claims that the geoparks' communities should be engaged in a bottom-up process. Through the explanatory method, two phases of research were traced. In the first phase, questionnaires, online and in person, were applied to 503 respondents born, resident and/or worker in Figueira da Foz older than 18 years old. The research was undertaken in order to understand the level of engagement with the aspiring geopark, the recognition of the geological heritage of Figueira da Foz, as well as the impact of a geopark on the region. In the second phase, outlined from the quantitative analysis of the previous data, a semi-structured interview was applied to the interlocutor of the aspiring Jurassic Geopark of Figueira da Foz, a researcher in geoparks and one representative of each of the five national geoparks. A content analysis of the interviews was done. The analysis of data related to the engagement activities implemented to promote the recognition of the appliance of Figueira da Foz to a UNESCO Global Geopark, indicates they were mainly informative and consultative (as it happens in other established Portuguese geoparks). The results seem to suggest that the initiatives undertaken allowed the population to feel engaged in the application process of Figueira da Foz to be recognised as a UNESCO Global Geopark.

Keywords Geoparks · Public engagement · Geoscience awareness · Survey · Citizenship · Figueira da Foz

Introduction

There has been an increased recognition of the importance of heritage as part of the identity and sovereignty of nations. There is also a growing awareness of heritage conservation through the involvement of populations using bottom-up, cooperative and co-management processes. Examples of these conservation efforts are programmes such as UNESCO Global Geoparks, which ensure the viability and success of natural heritage conservation, the education of visitors through geotourism activities, while guarantying that local communities benefit from the establishment of such programmes, as connoisseurs of the region and promoters of local economic development, and participate in building harmony between the population and natural heritage [1–5].

This regional development strategy aims to protect, manage, and promote landscapes of extraordinary value with three main objectives: conservation of geological heritage, education of the visitors through geotourism activities and inhabitants [6].

UNESCO Global Geoparks are established through a bottom-up approach involving all stakeholders, including local and regional authorities, stakeholders, community groups, local organizations, and other stakeholders. This process requires a firm commitment from communities, a strong local partnership, with long-term political and public support, and the development of a comprehensive strategy that meets all community goals, showing and protecting the area's geological heritage [3–5, 7].

The failure to engage in community involvement is also the failure to respond to the conditions required for a region to be a UNESCO geopark because geoparks do not exist isolated from the population [8, 9] and communities are interested parties whose values need to be considered to avoid conflicts in the management of natural resources [2, 5, 10].

There are also studies about the various interpretations of participation levels that facilitate a better understanding of how to involve the community in the development process [11].

Considering these aspects, and despite UNESCO requiring a bottom-up approach to empower local communities in geoparks [2–5, 7], community perspectives are largely absent from academic studies on geoparks [12, 13]. In most of these studies, the physical landscape, marketing actions and activities at schools are the predominant objects, assuming that the landscapes of geoparks are intrinsically valuable and the knowledge increase improves the awareness of the community about the significance of geoparks [12–15].

By the above, it is justified to carry out an investigation that reflects the bottom-up approach, seeking to peer with the population of Figueira da Foz their feelings about the creation of a geopark and its involvement in the establishment of this complex and multidisciplinary structure.

Based on the geological and geomorphological characteristics long acknowledge and to fight the tourist seasonality of the municipality, Figueira da Foz decided to proceed with an application to UNESCO. The beginning of the work towards the recognition of Figueira da Foz as a UNESCO Global Geopark took place in 2017. This was an excellent opportunity for this study to follow the whole application process from the beginning, in particular the subject of population involvement. Starting from this point and acknowledging, through bibliographic analysis, the lack of studies on the direct involvement of local communities in the creation and maintenance of geoparks, the following research question was formulated—Is the population of Figueira da Foz (civil society and stakeholders) be involved in the application of its territory to UNESCO Global Geopark?

As a final objective, it is intended to contribute to a growing public engagement in the creation of these spaces of scientific disclosure, encouraging all those involved in the process to develop a collaborative effort to monetize a heritage that is intended global.

Geoparks

Concepts and Examples

A geopark is a "*territory with well-defined limits that has a large enough surface area for it to serve local economic development. It comprises a certain number of geological heritage sites (on any scale) or a mosaic of geological entities of special scientific importance, rarity or beauty, representative of an area and its geological history, events or processes. It may not solely be of geological significance but also of ecological, archaeological, historical or cultural value*" [3].

This is a territorial management strategy that recognizes the uniqueness and importance of geodiversity as a matrix, that conditions fauna and flora, as well as the way the human species relates to space [16]. Because geoparks are intended to have the maximum influence on the living conditions of the inhabitants and the environment, the ecological, archaeological, historical and cultural heritage should be included simultaneously in a spirit of complementarity and holistic view of the territory [17]. For this reason, the promotion of cultural and immaterial aspects are also of prime importance for geoparks, through geotourism and the development and stimulus of local products, crafts and services, enhancing local economic growth and the creation of new job opportunities [16].

According to UNESCO, in April 2021 there were 169 global geoparks recognized by this entity, distributed in 44 countries, among them are five Portuguese geoparks: the Naturtejo Geopark, the Arouca Geopark, Azores Geopark, Geopark Terras de Cavaleiros and Geopark Estrela [4]. In the application process, Portugal has four potential geoparks: Viana do Castelo Littoral Geopark, Geopark Oeste, Geopark Algarvensis and Geopark Jurassic of Figueira da Foz (until July 2019, becoming Atlantic geopark since then).

Public Engagement in Geoparks Proposals

Placing the local community at the heart of the strategy through a bottom-up engagement process, UNESCO Global Geoparks build their approach based on active community participation, with the aim of improving population engagement, in a structured and strategic development plan of the territory [7, 12, 17]. This approach has been a key element for balancing strategies for conservation and management of natural resources, equity and local empowerment, with positive effects on the local economy [18] building cohesion while achieving results, with increased self-organization, resilience and a sense of community pride [7, 19].

This role requires a work of interconnection between the governing parties, the different economic agents, artisans, schools and other social groups, and requires the establishment of cooperation networks that is translated in the growth of goods and services in the local economy and society [7, 20].

However, some authors have wondered about the capacity of developing policies related to the social role of geoparks [21–26] and reflect on the legitimacy of the inhabitants being often left behind [12–15]. Girault [15] adds that the proliferation of intermediaries in the application processes, the standardization of participatory models, top-down models and aggressive advertising strategies currently accepted in some countries, are deconstructing the core of the geopark concept initially proposed by UNESCO.

Types of Public Engagement

There are several ways of describing the different types of public involvement, and the processes may be more or less participatory, informative, interactive and proactive, but whose divergences in the analysis of criteria for public commitment are still being discussed.

According to the International Association for Public Participation there are 5 levels of engagement: communicating (e.g. advertising campaigns, exhibitions), consulting (e.g. meetings, guided tours), including (e.g. public meetings, round tables), collaborating (e.g. working groups) and empowering (e.g. delegation of powers).

The existing typologies characterize, mainly, the way of involvement according to two models: top-down, initiated or led by people with formal power in the decision, and who aim to empower less influential and with different perspectives stakeholders, contributing to decisions, or bottom-up, which is initiated or carried out by citizens with limited decision-making authority [27, 31].

According to Arnstein [28, 29] and Wilcox [30] there is a ladder of public participation, whose most basic levels match a lower level in public involvement, while the higher categories match a greater empowerment and degree of participation of citizens.

On the other hand, there are authors who claim that these processes are interdependent, and that both forms of participation must be in constant balance and committed in co-producing [18, 27, 31, 32]. The involvement is enhanced by the level of motivation that citizens have about the subject and the incentive given to participation. It is based on co-production through multi-direction conversations, with multiple audiences and multiple types of actions [18, 33].

However, the authors agree that there are two major levels of participation, (a) pseudo-participation, which comprises more passive levels of involvement called domestication (including information, therapy and manipulation) and assistance (covers the consultation and pacification of citizens), and (b) genuine participation through cooperation (achieved through partnerships and delegation of power) and citizen control (empowerment of citizens from the definition of the problem to the solution) [28].

Genuine participation occurs when the inclusion of citizens occurs (including the marginalized), trust amongst those involved, equality in the treatment of opinions, transparency, independence and impartiality in the process, commitment of all, accessibility, knowledge sharing, information congruence, early involvement, accountability, productivity and response towards the contributions [32].

The Aspiring Geopark of Figueira da Foz—Portugal

Figueira da Foz's geological history represents an evolution period of approximately 180 million years, marked not only by the many evolution stages of the Lusitanian Basin through the Mesozoic, but also the geodynamic context of the most recent Cenozoic sediments.

It is possible to analyse in detail a large slice of the only existing basin within the North Atlantic margin containing a wide surface exposure, allows the access of certain historical testimonies of Earth's span, that by its preservation and representation of the geological systems' dynamics which generated them, has a worldwide patrimonial value and recognition. These testimonies are essential to attract a considerable number of curious people, as well as teams of professionals and specialists within a whole variety of fields to perform investigations at national and international levels [34].

The continuous record on ammonite assemblages including taxa of Boreal and Mediterranean affinities enabled the establishment of an accurate biostratigraphic framework for the Middle Jurassic. This set of factors translates into a significant increase in their potential for correlation at a global scale [35], allowing to define two points of global interest based on paleontological and stratigraphic standings. The first one, concerns the Global Stratotype Section and Point (GSSP) of the Bajocian Stage, located in a particular section near Murtinheira Beach, becoming an international outcrop reference in 1996 [36, 37]. The second one corresponds to the Auxiliary Stratotype Section and Point (ASSP) at the base of the Bathonian at Cabo Mondego (section "Geoparks"), 7 km north of the city of Figueira (Fig. 16.1).

Biological diversity is significant, especially the one protected within the Natura 2000 Network and the Ramsar Convention, precisely the coastal habitats and halophilic vegetation, maritime and inland dunes, freshwater habitats, heaths and shrubs from temperate zones, sclerophyll scrub, natural and semi-natural herbaceous formations and other typical species from Europe's temperate forests.

For a better understanding of the occupation of the territory, it is important to have in mind that in place of the rice fields, which now occupy the lower Mondego, there existed a navigable delta, the old Mondego, endowed with a geomorphological condition that promoted the human occupation of its banks. Santa Olaia, is an excellent description of permanence over time, where the overlapping of the anthropomorphic layers reminds us of successive occupations that have been forged over the ages [38]. The Phoenicians, who occupied these banks, profited greatly from the navigability of the Mondego, on the other hand, the Romans managed to sail to Coimbra by

Fig. 16.1 Part of Cape Mondego, in which the auxiliary section of the Bathonian Stratotype (ASSP) stands out

sea [39]. However, the human occupation of the Munda (name used by the Romans for the Mondego River), and its alteration over time, cannot be dissociated from the human occupation, the animal husbandry and cultivation of the early Neolithic sedentism [40], the production of Chalcolithic ceramics, the commercialization and transformation of the Phoenician metals of the Iron Age [41], the construction of roads and villages of the Roman conquest [42], the stabilization of medieval villages and military forts or, more recently, the production of rice and salt, very relevant for the cod industry.

When it comes to industrial heritage, Cape Mondego appears as a high-profile coal mining operation in the country [43]. We find in the landscape the most distinct marks of time, from dinosaur tracks, to prehistoric civilizations, to the discovery of coal, to the reminiscences of the Industrial Revolution, and to mining exploration craters that have changed the morphology of the place. The industrial complex develops along the coast road that connects the Figueira da Foz's waterfront to the Murtinheira road. The coal mines, which begun in 1750 and were closed in 1967, are more than 3 km long [44]. The industrial structure includes a built structure which, in addition to coal mining, has been used for the production of whitewash, cement, glass, briquettes and electricity. The study of this place allows a reliable contextualization of the evolution of human techniques from the industrial revolution to the present day, taking as its motto the use of natural resources [45]. In addition to the industrial heritage value is added the geological and paleontological interest certified by the classification of the Cabo Mondego Natural Monument and the Global Stratotype Section and Point of Bajociano.

In order to promote the public embedding in the application process of the aspiring Jurassic Geopark of Figueira da Foz, in 2018 Trincão and colleagues [46] applied some communication/engagement strategies, including a dinosaur exhibition, interpretive boards throughout the most iconic waterfront avenue, guided tours, Geopark Hour (to clarify the geopark's project and expose participants to new concepts and perspectives), activities designed for school audiences, local media coverage and small marketing campaigns.

Methodology

Research Plan

This case study aimed to investigate the engagement of Figueira da Foz's population in the creation of a UNESCO Global Geopark in the region through (i) identification of the activities designed for public participation and comprehension the means the population of Figueira da Foz is being engaged in the application to the UNESCO Global Geopark; (ii) analysis of the speech of investigators and coordinators of national geoparks and comparison of results gathered from the population of Figueira da Foz.

The Research Instruments

To answer the investigation problem, a research was conducted in two phases. On the first phase, questionnaires (quantitative analysis) were applied to the population (civil society, investors and entrepreneurs, representatives and employees of the local political power, security forces and other groups) natural-born, resident and/or worker at Figueira da Foz, older than 18 years old. In the second phase, designed with the information gathered from the previous phase, it was applied the technique of inquiry by semi-structured interview. The interviews were applied to (i) an interlocutor of the Figueira da Foz geopark application; (ii) a researcher; (iii) one representative of each of the 5 national geoparks already established.

Questionnaires

A questionnaire was prepared with 22 questions, 20 of which with closed answers, mostly multiple choice and Likert scale, and two open questions. In addition to personal characterization (age, educational qualifications, parish and occupation), respondents were asked about the concept of geopark, communication strategies and participation in the aspiring Jurassic Geopark of Figueira da Foz (based on Trincão [46]), the perception of engagement, awareness of the natural and cultural aspects of the territory and the impact of the future geopark on the region's economy and tourism. The questionnaire did not include any type of personal identification data.

A pilot survey was given to 12 people, over 18 years old, with diverse education background (sciences, humanities, economics, and arts), various occupations and different levels of literacy, and the method of spoken reflection was applied. Based on the feedback received by the test group, the final version of the surveys was prepared.

The questionnaire designed for this work was applied either electronically and face-to-face, during April and May 2019, to respondents born, residents and/or workers at the Municipality of Figueira da Foz and over 18 years old.

After collecting responses during 60 days (with advertising reinforcement every two weeks), 403 responses were collected electronically, and 100 responses obtained through face-to-face questionnaires.

Interview

The script of the interviews carried out was organized according to a set of six thematic blocks, according to the goals of the investigation and based on the results of the analysis of the questionnaires mentioned above, aiming to compare the opinion of the interviewees with the data obtained in the questionnaires.

In this study, seven people were interviewed, namely: an interlocutor of the application to the aspiring Jurassic Geopark of Figueira da Foz [ID1], a geopark researcher [ID7], and representatives of the five national geoparks [ID2-ID6].

The interviews took place between October and November 2019 and had an average duration of 40 min.

Accuracy was ensured by two researchers (the Ph.D. student and a member of the advisory team).

Sample

The sample consisted of 503 individuals, aged between 18 and 79 years old, the most frequent age group corresponding to 40–44 years (n = 91, 18.1%). Most respondents were female (n = 297, 59.0%), and born in Figueira da Foz (n = 265, 52.7%). The best represented parish is the largest and most urban (Buarcos and São Julião) (n = 212, 42.1%), and the most suitable type of residence is the permanent one (n = 232, 92.8%). Regarding educational qualifications, 39.2% (n = 197) of respondents were graduates, followed by secondary education, with 28.4% (n = 143). In professional terms, teachers appeared in greater number, corresponding to 21.6% (n = 99) of the sample, followed by office employees (n = 42, 9.2%), and specialists in physical and mathematical sciences (n = 33, 7.2%), representatives of local power, executive boards and senior managers of Public Administration (n = 30, 6.5%). The remaining occupations appeared in a minority form.

Results and Discussion

In most recommendations in texts that define geoparks, the UNESCO expresses the needs of communities (civil society and stakeholders) to create participatory movements that lead the bottom-up process of creating and maintaining geoparks [15]. In this respect, various activities for furthering knowledge and engagement among the population are organised, including heritage sites, museums, information centres, guided tours and visits, school outings, information leaflets, maps and seminars, among others. However, most geoparks promote capacity building workshops as a way to make geopark objectives known and to engage local residents with various experts [47].

Accordingly, only three questions from the questionnaire and responses from the seven interviewees were analysed. The analysis of the data allowed to obtain information to answer two research questions.

Issue 1: What Engagement Initiatives Have the Most Participation?

Bear in mind that a specific action does not always lead to participation in that action. To analyse this phenomenon, association tests were conducted between the variables that reflect knowledge of the actions implemented by Trincão and others [46] and their respective participation. One would expect that an analysis of the sample would find that in most cases the respondents with the highest participation in the activities would be those with prior knowledge of them. In this respect, the Chi-Square test enabled us to ascertain that in the case of the dinosaur exhibition ($\chi_1^2 = 75.23$; $p = 0.000$) and the boards displayed ($\chi_1^2 = 290.13$; $p = 0.000$); this was effectively the predominant trend with a significance level of 0.05. The same was not true for Geopark Hour ($\chi_1^2 = 126.39$; $p = 0.000$) or for guided tours ($\chi_1^2 = 97.40$; $p = 0.000$), where the tendency was the presence of respondents with no knowledge and no participation in the actions carried out (see Table 16.1).

When the researcher [ID7] and the other geopark representatives [ID2-ID6] were asked which strategies they consider to work best for engaging the population in geoparks, the responses focused mainly on engagement in schools through educational programmes, school outings, school projects and educational activities, conferences, clarification sessions with local government representatives, walks, participation in events organised by municipalities (such as handicraft markets and other fairs), scientific meetings, and investment in communication strategies.

[ID2] "*There has been some progress in this respect, but it has been much slower because for starters, people have their work, they are not centralised in a school. But there has been a set of various initiatives ranging from courses to projects, initiatives, organisation of events in which people are sought for their involvement,*

Table 16.1 Association between the knowledge and participation in the activities carried out

		Participated		χ_1^2	*p*-value
Was informed		Yes	No		
		n	n		
Dinosaur exhibition	Yes	**230**	195	72.53	**0.000**
	No	0	72		
Boards	Yes	**233**	63	290.13	**0.000**
	No	1	196		
Geopark hour	Yes	37	77	126.39	**0.000**
	No	1	**374**		
Guided tours	Yes	49	114	97.40	**0.000**
	No	3	**324**		

so the community is prompted to participate. (…). *The investment in education is strategic because we are educating future generations.*"

[ID3] "*Fundamentally, we have run a number of projects in some of the communities where we've been working, and then the work is carried out with schools, which has also had a significant impact as we are developing a set of initiatives, some of which take place throughout the academic year, and which end up leaving out some products that are then applied in subsequent years* (…) *especially those that take place every year because they ultimately become part of an events calendar; this repetition is what leaves a legacy of people who end up participating in activities repeatedly in various municipalities, creating a kind of "family" of geopark event participants.*"

[ID4] "*Then there are other important strategies, such as engaging people in festive activities where there's something such as a dance, song, concert, food, dinner,* etc., *and where afterwards there is a light introduction to the theme of the geopark.*"

[ID5] "*We understood right from the beginning that the major challenge has always been, and still is, engaging local populations. Let me give you some examples that have been carried out on several levels. There is a particular strategy that strikes me as radical, and that is education, the educational route* (…) *today we have a significantly wide implementation in schools in the local area, there have been weeks during which we visit a different school every day* (…). *Then, another area is population outreach, and this has been worked on at various levels, specifically with the creation of a series of conferences* (…). *We then had clarification sessions with all the presidents of the parish councils in the area* (…). *Another level relates to the potential for the geopark to participate in several events promoted by municipalities, in local festivals, such as the cheese or chestnut festival, the wool festival,* etc. (…). *Finally, I think traditional communication strategies, in this case social networks, presence in national magazines, our website, the way we communicate, the placement of physical communication structures such as billboards and promotional MUPIs* *have been strategies that we have been trying to use to reach the greatest number of people.*"

[ID6] «(…) *I would say there are two aspects: on the one hand, the dissemination and promotion by means of normal communication and marketing techniques, and on the other hand, by what is actually done, and this also draws attention and helps to promote geoparks.*(…)*. Another way is to reach specific target audiences. Instead of running activities for the general population, we try to reach target audiences such as students and schools in the area of economics, tourist entertainment companies* (…)»

[ID7] "*Regular news in the media is very important.* (…)*. Thereafter, I believe it is important to work with the educational community. I think it is very difficult to start raising expectations in the community before having an action plan, a team, funding, so that the project really has an established structure and people actually see something change in the municipality's strategy.*"

The activities that purportedly reached a greater number of individuals in Figueira da Foz were the dinosaur exhibition and the display boards on the waterfront. When asked which strategies they considered work best for public engagement, respondents immediately identified school communities as the main strategy, due in large part to their information-spreading effect. This strategy was not analysed for this paper, as the intention was to understand the degree of engagement of the municipality's adult population.

According to literature consulted, from the International Association for Public Participation (IAP2) to Arnstein [28, 29], the actions promoted during the first year of preparation of Figueira da Foz's Geopark application are considered as the basis of the various levels/types of public engagement. According to the IAP2 table, the activities are at the communicative level (the community is informed through news, advertising campaigns, exhibitions, and conversations in a unidirectional flow). In contrast, for Arnstein the initiatives informed (unidirectional flow in the top-down direction), as well as tried with limited success (as noted by the Geopark Hour and organised guided tours) to consult the population in a bidirectional direction (top-down and bottom-up) manner.

In a 2015 study, Fogg-Rogers and colleagues [48] noted that in an early stage of a science outreach project, adult audiences sought informal learning activities with a one-way dialogue in order to familiarise themselves with the topic, to learn and to become more informed, before participating in activities with a two-way discourse. The success of any actions taken implies resilience and dealing with resistance and obstacles, providing opportunities for dialogue, and monitoring the activities carried out in order to understand the impact of such actions and thus the reinvention and application of new strategies, taking into account the specific contexts and the understanding of what public involvement should entail [49].

Issue 2: Did the Initiatives Undertaken Promote the Engagement of the Inhabitants of Figueira da Foz in the Application of Their Region to Become a UNESCO Global Geopark?

Regarding Figueira da Foz's UNESCO Geopark candidacy, and perhaps due to the public reached, 53.1% of respondents were aware that an application was being prepared, but 57.2% were uncertain about their knowledge regarding the effort to promote it. It should be noted that 77.1% reported not feeling engaged in the application process, and 311 people (67.2%) did not see any news about it. However, 92.7% of respondents indicated that they support the creation of a UNESCO Geopark in Figueira da Foz, even though 59.2% did not know if citizens in general support this initiative.

Regarding this data, one of the interviewees states:

[ID2] "*I think the fact that 53% are aware is very significant; this shows that, in fact, communication has been somewhat effective, this strikes me as interesting.* (…). *13% is a significant number of engaged people, I would have thought that at this stage this number would be less than half of that.* (…) *a geopark that will potentially develop in this region will have grassroots support, with respect to the people who live in the local area, as well as very significant engagement from the beginning. I would say that if I asked these same questions today in the Portuguese UNESCO Global Geoparks, I would not get numbers of this nature, I would get much lower numbers.*"

Awareness of the geopark application process may be associated with knowledge of the actions carried out by Trincão and colleagues [46], for which Chi-Square tests were conducted, as shown in Table 16.2. The statistics showed that those who are aware of the application are most commonly those who visited the dinosaur exhibition and saw the boards on the Figueira da Foz waterfront, as opposed to the Geopark Hour and the guided tours, where it is more likely that those who knew about the candidacy did not participated in these actions. Regarding the population's general knowledge of the candidacy, significant associations were found between the display boards, where those who are unaware of the candidacy knew about the exhibition, the Geopark Hour and the guided tours, where there is a greater tendency to be unaware of both. As for the effort to promote and publicise the UNESCO Geopark candidacy, those who saw the boards did not know if this effort was made; for the Geopark Hour and the guided tours, it was more frequent not to have participated in both and not to know if the effort was made. With regard to the feeling of engagement perceived by respondents, there is significant association between participation in the Geopark Hour and the guided tours, where most respondents did not participate in them and also did not feel involved in the application. As for the appearance of the geopark initiative in the news, the Chi-Square test reveals that it is more frequent that respondents did not participate in the dinosaur exhibition and did not see any news, with the same being true for the visit to the boards on the waterfront, the non-participation in the Geopark Hour, and the guided tours (see Tables 16.1 and

Table 16.2 Association between awareness, dissemination, engagement and support of respondents regarding a geopark in Figueira da Foz and participation in the activities carried out

(continued)

Table 16.2 (continued)

	Participated							
	Exhibition		Boards		Geopark hour		Tours	
	χ^2_2	*p*-value	χ^2_2	*p*-value	χ^2_2	*p*-value	χ^2_2	*p*-value
Am aware of the application	9.34	**0.009**	28.44	**0.000**	28.34	**0.000**	16.74	**0.000**

(continued)

Table 16.2 (continued)

	Participated							
	Exhibition		Boards		Geopark hour		Tours	
	χ^2_2	*p*-value	χ^2_2	*p*-value	χ^2_2	*p*-value	χ^2_2	*p*-value
The population is aware of the application	2.01	0.367	6.06	**0.048**	25.49	**0.000**	13.77	**0.001**

(continued)

Table 16.2 (continued)

	Participated							
	Exhibition		Boards		Geopark hour		Tours	
	χ^2_2	*p*-value	χ^2_2	*p*-value	χ^2_2	*p*-value	χ^2_2	*p*-value
Efforts have been made to publicize the application	4.17	0.124	8.84	**0.012**	6.38	**0.041**	16.13	**0.000**

(continued)

16.2). In terms of support for the application, the most supportive respondents were those who were aware of the actions implemented, with the exception again of the Geopark Hour and the guided tours, where the tendency is not to have participated in these two actions, but still support the geopark candidacy.

When asked about the data presented and about the importance of the population's engagement in the creation of a geopark, some of the interviewees stated:

[ID1] "*We already understand that it is fundamental even for the UNESCO itself. To be considered a geopark, the population has to be fully engaged, which makes sense.*"

[ID2] "*Engagement has to be from everyone. The activities carried out by the management structure must reach all residents of the area.*"

[ID4] "*I think the more engagement there is on the part of the population, the greater the prospect of success. In summary, the more support you have from the*

Table 16.2 (continued)

	Participated							
	Exhibition		Boards		Geopark hour		Tours	
	χ_2^2	*p*-value	χ_2^2	*p*-value	χ_2^2	*p*-value	χ_2^2	*p*-value
Feel involved in the application process	3.89	0.143	0.64	0.728	17.25	**0.000**	16.58	**0.000**

(continued)

Table 16.2 (continued)

	Participated							
	Exhibition		Boards		Geopark hour		Tours	
	χ_2^2	*p*-value	χ_2^2	*p*-value	χ_2^2	*p*-value	χ_2^2	*p*-value
Have seen news about the future geopark	10.90	**0.004**	16.31	**0.000**	28.09	**0.000**	32.76	**0.000**
Support the creation of a geopark	19.30	**0.000**	10.40	**0.006**	5.80	0.055	13.31	**0.001**

(continued)

Table 16.2 (continued)

	Participated							
	Exhibition		Boards		Geopark hour		Tours	
	χ_2^2	*p*-value	χ_2^2	*p*-value	χ_2^2	*p*-value	χ_2^2	*p*-value
The population supports the creation of a geopark	11.28	**0.004**	4.53	0.104	4.25	0.119	6.04	**0.049**

people, recognition, engagement, pride, the better, but my overriding opinion is really on the advantages of building a winning, inventive team with the ability to do new things, to run innovative and communicative projects."

[ID6] "*The geopark concept, as defined, assumes that there is engagement of people living in the area from the very beginning, so in theory, and in the geopark concept itself, in order to have a geopark, the people must be engaged in the creation of the geopark.*"

[ID7] "*Engagement is very important because the geopark is for the people who live there. The geopark is not for tourists, or for geologists, but for the communities that are located within the geoparks. They are the main beneficiaries of being placed within, of living in, a geopark. Therefore, it makes perfect sense for communities, partners, and stakeholders to determine what the geopark will be like, how it will operate, how it will be implemented, how it will be driven forward. The geopark is theirs and it is for them, hence the importance, and that is why they have to be engaged.*"

As acknowledged by the interviewees, the engagement of people who live within the geopark is fundamental for its creation. Furthermore, in order to have engagement, there has to be knowledge of it, and this is what the data from the quantitative analysis suggests: there seems to be a direct relationship between knowledge of the geopark candidacy and participation in the activities undertaken.

Geoparks foster the participation of communities as a means of conservation, but also as a way of increasing per capita income and reducing unemployment and migration levels. Geoparks serve to conserve the environment, to educate residents and visitors about Earth science, and to promote sustainable local economic development based, in part, on geotourism. To this end, the UNESCO states that communities must be engaged from the start of the process by means of a bottom-up system, through economic balance and human need. When analysing the discourse of those responsible for the national geoparks that are already established, the presence of a strong orientation of engagement activities for schools can be detected. It is particularly appealing to engage the younger tiers of society since, as well as being open to knowledge, the school environment is favourable for the transmission of knowledge on a large scale. It is necessary, however, to conduct follow-up studies to understand whether the apparent affinity of the students comes from geopark actions or whether it is an intrinsic effect of age and place of residence. What about the adult audience outside of the school context? What has been done in this respect? The examples presented focus on annual festive events, such as popular festivals, markets and fairs, conferences, workshops, clarification sessions with local authority representatives, presence in the media and advertising. Turning back to the IAP2 spectrum and Arnstein's ladder of public participation, the national geoparks initiatives that have already been established coincide with the levels of action taken by Figueira da Foz as preliminary actions of public engagement in the candidacy: communicate, consult and, uniquely, include (workshops are cited, although it is unknown what type of workshop). Doubts remain as to whether strategies have been implemented, and which ones, to apply the bottom-up management model that the UNESCO intends for geoparks, and to set up citizen-led working groups that lead to the delegation of power to the community. Stoffelen and Vanneste [50] showed that internal marketing can be successful and can improve community support for regional development policies, although this sense of engagement can be misleading. Some studies show that, despite a nominal increase in local companies, there is actually little power on the part of the population and smallholders [49, 51–53]. Community engagement is an essential facet, and its complexity should not be underestimated by any of the entities involved [1].

Conclusion

According to different theoretical approaches concerning public engagement, the initiatives carried out in the application of the Jurassic Geopark of Figueira da Foz to a UNESCO recognition, were mostly informative (dinosaur exhibition, interpretive boards, guided tours, regional media, and other small public actions), and consultive (Geopark Hour), in an attempt to implement bidirectional public participation. The activities that apparently had the most impact were the proximity actions with small groups of citizens (Geopark Hour and guided tours), compared to mass actions (dinosaur exhibition, interpretive boards).

With these results, it seems legitimate to assume that there is an association between the initiatives carried out and the engagement of the population of Figueira da Foz in the application of their territory to a UNESCO recognition, in other words the population of Figueira da Foz is embedded in the application, although in a basis level.

There is no difference in the typology of activities carried out to promote the engagement of the adult population in the aspiring Geopark of Figueira da Foz and in the geoparks already established. The activities are mostly at communication and popular consulting level, instead of stimulating active involvement, interaction or empowerment. When analysing the interviewees' speech, one notices a speech focused on engagement in a territorial marketing logic, in particular territorial branding.

Societal embedding has become a common and globally widespread concept; however, it is premature to support that a new era of population engagement replaced the traditional hierarchical structure of decision-making. This is a long path that requires from all agents an increased effort to promote this change among the population.

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Chapter 17
Environmental Education in Naturtejo UNESCO Global Geopark (Portugal): A Nature-Based Approach

Maria Manuela Catana and José Brilha

Abstract UNESCO Global Geoparks (UGGps) are excellent teaching opportunities as outdoor classrooms and incubators of sustainable development, sustainable lifestyles, appreciation of natural and cultural diversity, and promotion of peace. Naturtejo UGGp offers educational programmes addressed to the school public (formal education) since 2007, focused on geosciences education for sustainability. These programmes intend to contribute to the conservation and promotion of the local natural and cultural heritage, as well as to the sustainable development of this Portuguese territory. The educational activities are promoted with different partners and are addressed to students and teachers from the kindergarten to the university. Most of the activities are outdoor activities with the purpose to re-connect young people with nature. This link has been weakening particularly in larger towns but it is essential to re-establish an emotional bound between future responsible citizens and the natural environment.

Keywords Education for sustainability · Educational programmes · Formal education · Geosciences education · Outdoor learning · Educational resources · Geological heritage · Natural heritage · Cultural heritage

Introduction

The Man and Biosphere Programme, the Convention Concerning the Protection of the World Cultural and Natural Heritage and Global Geoparks are the three UNESCO's nature-related mechanisms to promote the implementation of Agenda

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2030 for Sustainable Development, adopted by the United Nations in September 2015. The Agenda 2030 comprises 17 Sustainable Development Goals (SDGs) and 169 targets, which are deeply embedded on the economic, social and environmental dimensions of sustainable development [1].

UNESCO Global Geoparks (UGGps) are territories where sites and landscapes of international geological relevance are managed on the base of a holistic concept of conservation, education, and sustainable development [2]. There are 169 UGGps in 44 countries distributed by all continents (numbers as of July 2021). UGGps are perfect laboratories to implement and contribute to achieve the SDGs, as shown in the UNESCO's brochure "UNESCO Global Geoparks contributing to the Sustainable Development Goals—Celebrating Earth Heritage, Sustaining local Communities" [2]. The results of a survey showed that the SDG 4—Quality education—is the most important SDG to sustain UGGps relevant projects [3].

Naturtejo UNESCO Global Geopark has integrated the European and Global Geoparks Network under the auspices of UNESCO in 2006 and is located in central Portugal near the eastern Portuguese–Spanish border [4]. The Naturtejo's territory comprises 5.060 km^2 and includes seven municipalities: Castelo Branco, Idanha-a-Nova, Nisa, Oleiros, Penamacor, Proença-a-Nova and Vila Velha de Ródão, with 96.500 inhabitants (Census 2011) [5]. As in any other UGGp, Naturtejo has a significant number of geological sites with special scientific, aesthetic, and educational relevance representing the last 600 million years of the Earth's history and evolution of life [4]. In this territory the archaeological, ecological, historical and cultural heritage is also of very high relevance [2]. The management structure of this geopark—"Naturtejo—Empresa de Turismo"—is an intermunicipal major state-owned company established in 2004.

The Role of UNESCO Global Geoparks in Promoting Geosciences Education for Sustainability

All UGGps must develop and promote educational activities for people of all ages, in order to raise awareness of geological heritage and its relationships with other aspects of natural and cultural heritage. Thus, the policies and educational actions concerning geoconservation are very important, either in the school context (formal education) or addressed to the general public (non-formal education). In this work the focus will be the educational activities promoted by the Naturtejo UGGp for the school public (formal education). UNESCO Global Geoparks are excellent tools to assist schools as outdoor classrooms and to be incubators of sustainable development, healthy lifestyles, appreciation of the natural and cultural diversity, and promotion of peace [6, 7].

The analysis of the data obtained with an online questionnaire answered by seventy-three UGGps from thirty-five countries around the world allowed the characterization of the role played by geoparks in the promotion of geosciences education for sustainability through educational programs specifically addressed to the school community [6]. Education is actually one of the pillars of UGGps, and for this reason, most geoparks have a specific educational department in which spends about one-third of the annual budget of the geopark. The responsible person of the educational department has a scientific background on geology and has a permanent contract with the management structure of the geopark. Of the seventeen SDGs (AGENDA 2030), the most explored in educational activities are (in descending order) “four—quality education,” “fifteen—terrestrial ecosystems and biodiversity,” “eleven—sustainable cities and communities,” “thirteen—combating climate change,” “three—healthy life.” The theme “climate change” is a topic addressed by many geoparks, following the Declaration of Shimabara approved during the 5th International Geoparks Conference held in Japan in 2012 [6].

The Educational Strategy of Naturtejo UGGp—“Geonaturescola”

The educational programmes of Naturtejo UGGp are based in the geosciences education for sustainability paradigm and intend to contribute to the conservation, promotion and enhancement of the natural and cultural heritage of the geopark, as well as to the sustainable development of its whole territory [4, 8]. These programmes started in the school year of 2007/2008 and have been getting updated since then. The first edition of these programmes was awarded with the “Ecotourism Award 2008” by Skal International, in the category “Educational Programmes—Media”. Skal International is one of the largest international associations of travel and tourism professionals, created in 1934 [8].

The topics addressed in the educational programmes are adapted to the national curriculum. In Portugal, geology is taught in several years of the basic and secondary school system, which gives the opportunity to teachers to apply the Naturtejo’s programmes in different moments. For instance, when the topic is about the diversity of rocks, there is one specific activity in the geopark focused on this.

The educational value of the geological heritage of Naturtejo UGGp is corroborated by its inclusion as an educational resource in the national curriculum. Questions about its geoheritage have already appeared in national exams addressed to secondary school students [8] and some textbooks of natural sciences (7th grade) present texts and photographs of the geopark’s geodiversity, besides being suggested as a relevant destination for field classes.

The Geopark's Educative Service

The Naturtejo UGGp has recognised the importance of the education pillar since its very first beginning as a geopark. An educative service was setup in the school year 2007/2008 with a coordinator properly trained for the job (Bachelors on Biology and Geology Teaching and a Master Degree on Geological Heritage and Geoconservation). This coordinator has the responsibility to design, implement and assess the educational activities of the geopark and also to train other monitors involved in assisting educational activities. These monitors receive a theoretical training on national curriculum topics and field training before they start to work with students and teachers.

The objectives of the geopark's educative service are [8]:

- to be a complement to the national curricula;
- to help teachers to diversify the type of strategies they use to teach geosciences topics and others;
- to encourage a healthy direct contact with nature;
- to raise awareness of the importance of the protection and conservation of natural and cultural heritage;
- to promote actions to value, conserve and improve the environmental conditions;
- to promote the use of scientific instruments associated with field work;
- to foster a direct contact with the objects of study (for instance, fossils);
- to generate significant learning;
- to increase scientific literacy;
- to contribute to active citizenship.

The primary target groups are students and teachers of preschool, primary, secondary, and higher education, vocational education and senior universities within Naturtejo's territory and from other Portuguese institutions. Some programmes are also adapted to foreign students. The programmes cover not only topics included in geology and biology disciplines, both also other disciplines such as Geography; Environmental Education; History; Physical Education; Tourism (of Nature); Rural Development; Marketing, Land-use Management; Protected Areas; Portuguese; Physics; Chemistry. Optional nature sports activities included in some programmes are organised by private companies partners of the Naturtejo UGGp [8].

Nowadays, the educative service—"Geonaturescola" ("Geonaturschool") [9]—has 30 partners including two universities and one researcher centre, a teachers training centre, a NGO, seven private companies, 12 museums/science and environmental interpretation centres, two protected areas, the Tejo/Tajo International Transboundary Biosphere Reserve, the National Forum of UNESCO Global Geoparks, and the National UNESCO Commission.

Educational Resources of Naturtejo UGGp

The educational programmes of the geopark are obviously based on the natural and cultural resources of the territory, selected for their high educational value. In addition, these programmes also include interpretative centres and museums, walking trails and a boat/kayaks trip (Table 17.1) [8, 9].

Thirteen geosites out of the 176 geosites inventoried in the whole geopark were selected to be included in educative programmes [10], together with nine interpretative centres/museums out of the 40, and eight walking trails out of the 22. The boat/kayak trip is offered at the "Portas de Ródão" Natural Monument, where the Tagus river crosses a quartzite ridge in a dramatic landscape.

In addition to these resources, the educative service has also other resources that are used to help the teaching/learning process, such as:

- Illustrations and photos used in guided field trips;
- Models of trilobites, *Cruziana* and other fossils;
- Fossil replicas;
- Booklets and field trip guides for students and teachers [11];
- Scientific papers related with specific aspects of each field trip;
- Children's books and PowerPoint presentations;
- Games and puzzles of the geological map and geosites;
- Songs;
- Rock, fossil, and mineral collections;
- "Litoteca do Geopark Naturtejo"—box with 27 rock samples of the geopark.

Virtual educational resources produced by the geopark staff in partnership with trainee students of the Polytechnic Institute of Castelo Branco are also available, both on the geopark's website (www.naturtejo.com) and on the microsite dedicated exclusively to educational programmes "Geonaturschool" (www.geonaturescola.com), such as:

- "Litoteca virtual do Geopark Naturtejo"—virtual box with rock samples;
- Virtual visits to Segura and Monforte da Beira mines;
- Interactive simple games (crosswords, puzzles, quizzes).

Due to Covid-19 pandemic and to the fact that schools had to quickly convert the teaching methods, in 2020 a new tab was created on the geopark's website ("NaturtejoGeoparkAtHome") (https://naturtejo.com.casa.php) where links to online resources were gathered, either produced by the geopark or by other organisations.

Regarding the production of educative resources, it is worth to mention the results of the participation of Naturtejo UGGp in two European projects.

"Field Geosciences Teaching Module: Geoparks and Geosites—Naturtejo Geopark" [12] presents six geosites of the geopark and include documents for teachers (field teaching activities planning, presentations) and for students (worksheets). This resource is available in Portuguese and English and was one of the outcomes of a Lifelong Learning Programme—COMENIUS project, held between 2010 and 2013.

Table 17.1 Main resources of the Naturtejo UGGp used in educational programmes

	Educational resources of the geopark	Main theme
Geosites	Penha Garcia Ichnological Park	Palaeontology
	Portas de Almourão Geomonument	Fluvial geomorphology and tectonics
	Zêzere Gorge	Fluvial geomorphology
	Segura Mines	Mining
	Inselberg of Monsanto	Granite geomorfology
	Ponsul's Fault Scarp	Tectonics
	Fossil Logs of Vila Velha de Ródão	Palaeontology
	Erges River Canyons	Fluvial geomorphology
	Fraga da Água D'Alta Waterfall	Fluvial geomorphology
	Portas de Ródão Natural Monument	Fluvial geomorphology
	Granite Landforms of Gardunha	Granite geomorphology
	Conhal do Arneiro Gold Mine	Ancient mining
	Roman Mining Complex of Presa	Ancient mining
Interpretative centres and museums	Environmental Interpretative Centre of Castelo Branco	Biodiversity
	Interpretative Centre of Rock Art of the Tagus Valley	Archaeology, geology and palaeontology
	House of Arts and Culture of Tagus	Palaeontology
	Stonemason's Museum	Granite quarrying and uses
	Lands of Idanha Biodiversity Interpretative Centre	Biodiversity, rocks and ancient mines
	Raiano Cultural Centre	Agriculture
	Fossils House of Penha Garcia	Palaeontology
	Municipal Museum of Penamacor	Archaeology
	Living Science Centre of the Forest	Forest
Walking trails	Gardunha Trail	Granite geomorphology
	Mines Trail	Mining
	Fossils Trail	Palaeontology
	Boulders Trail	Granite geomorphology
	"Conhal" Gold Mine	Mining
	Orvalho GeoTrail	Fluvial geomorphology and tectonics
	Secrets of "Almourão" Valley	Fluvial geomorphology and tectonics
	Travel by the Earth Bones	Fluvial geomorphology and tectonics

Fig. 17.1 Teachers participating in a TeachOUT App Workshop at Inselberg of Monsanto geosite

"TeachOUT App" allows teachers to create their own exercises in partnership with teachers of other disciplines, to add a number of multi-sensory contents (e.g. treasure hunts, questionnaires, observation, listening, recording short films, works with maps), and to enrich their usual classroom work with a classroom in nature (Fig. 17.1) [13]. This app was produced under the scope of the ESTEAM Project (www.esteam.project.eu), co-funded by the ERASMUS+ Programme [14].

Types of Educative Programmes

In the school year 2020/2021 three educational programmes were offered: "School meets the Geopark", "Geopark goes to School" and "*Anim'a Rocha*" [15, 16].

The "School meets the Geopark" programme is intended for students from Portuguese schools and also from foreign schools, with some adaptations [15]. In order to promote this programme in schools located inside the geopark, students coming from these schools benefit from discounts on these activities. This educational programme is based on twelve interdisciplinary field trips of half a day or one day duration and two interdisciplinary field trips of two or more days duration (Fig. 17.2).

The "Geopark goes to School" programme is mainly addressed to schools of the Naturtejo's territory [16]. It consists of two field trips and eight workshops that take place in the classroom" [17]. Both the field trips and the workshops are offered free of charge for schools located in the geopark, with the exception of the workshop about fossils.

Fig. 17.2 Students participating in a field trip of the educational programme "School meets the Geopark" at Penha Garcia Ichnological Park geosite

The "Anim'a Rocha" programme is only addressed to schools located inside the geopark [18, 19]. This programme comprises several possible activities such as:

- Annual multi-stage projects (e.g. activities pre-field trip in the classroom; field trips; workshops; project work; exhibitions/presentations of the project outcomes) (Fig. 17.3) [19];
- Temporary exhibitions and associated educational activities;
- Celebration of thematic days/years (e.g. International Earth Day/National Geological Heritage Day, World Environment Day, Day of the Native Forest (Fig. 17.4));
- Specific contests addressed to Portuguese geoparks and co-organized by the National UNESCO Commission and the Portuguese Committee for the UNESCO International Geosciences Program (IGCP) [20] about environment and sustainability topics (Climate change and biodiversity; Natural resources for sustainability; The water that unite us; How to improve the environmental quality of my community; Desertification; It is the soil that sustains life). These contests include exhibitions and presentations of works done by students and student exchange between geoparks, usually implemented during the European Geoparks Week/Landscape Festival.

In addition to these activities addressed to students, some educative programmes are also focused on teachers, namely training courses (e.g., Naturtejo UGGp as an educational resource; Geodiversity and biodiversity of Naturtejo UGGp), seminars, workshops and field trips. Teachers from kindergarten to high school come from schools located inside and outside the geopark and are challenged to create their own educational resources to use with their students.

Fig. 17.3 Activity of gathering litter along the Ponsul river during a field trip of the “Project rivers” related to “Anim’a Rocha” educational programme

Fig. 17.4 Celebration of the Native Forest Day with tree planting included in “Anim’a Rocha” educational programme

Promotion and Evaluation of Educational Programmes

An effective promotion of educational programmes is crucial for its success. The Naturtejo geopark tries to guarantee a widespread information about its educational offer, namely through:

- Direct contact with teachers;
- Emails sent to schools;
- Edition of printed and online booklets;
- Social media;
- A specific microsite (www.geonaturescola.com) dedicated to educational programmes under the main geopark's website (www.naturtejo.com) [9].

It should be noted that there is a contact and a registration forms in the microsite for the field trips included in the "School meets the geopark" programme.

The evaluation of the educational activities is based on the feedback given by the monitors of the geopark staff that were leading the activities and also on the data received through paper-based satisfaction surveys filled by teachers [9]. In the early years of the organisation of educational activities, students also filled satisfaction surveys but the very high number of questionnaires discouraged this procedure.

The number of Portuguese students and teachers that have participated in educational activities of the geopark is shown in Figs. 17.5 and 17.6. It should be noted that some students and teachers participated in more than one activity per school year and on different occasions.

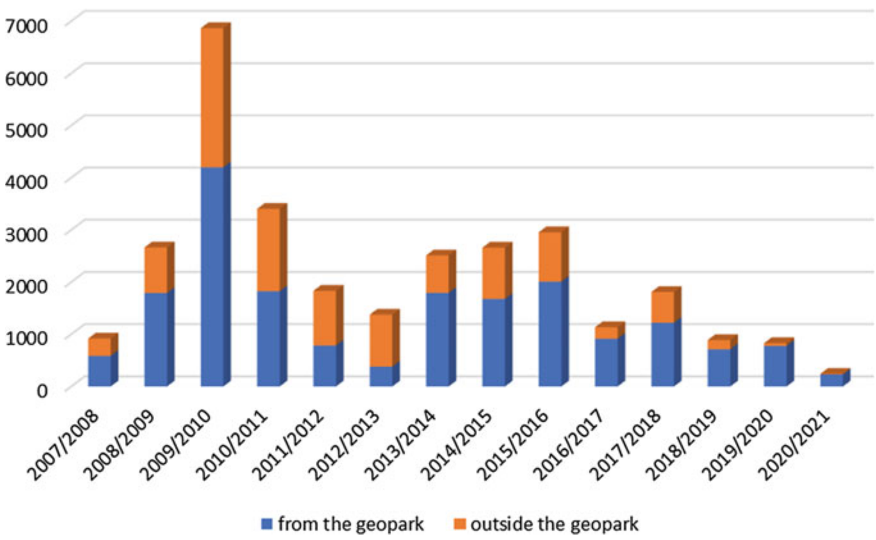

Fig. 17.5 Number of Portuguese students in educational activities, coming from schools located inside (blue) and outside (orange) the geopark

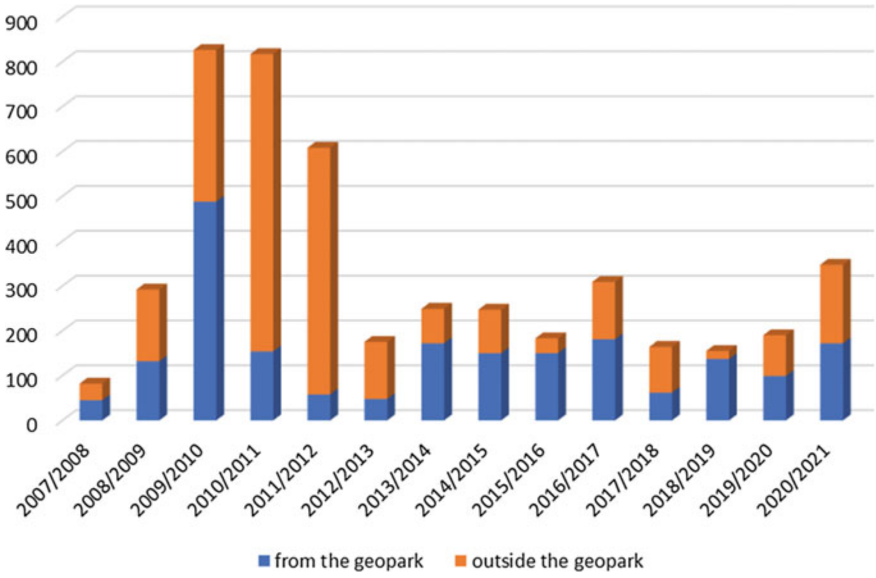

Fig. 17.6 Number of Portuguese teachers in educational activities, coming from schools located inside (blue) and outside (orange) the geopark

Both figures show that the number of students and teachers involved in Naturtejo's educational programmes is not uniform along the years. There are several factors that explain the variation of these numbers, namely:

- Existence of special events that temporary attract a higher number of students/teachers. This happened in 2010/11 when the geopark offered "Dino-Expo", a temporary exhibition that attracted a high number of schools from all over the country;
- The economical context of the country. During 2011/2012 and 2012/2013 the country faced a severe austerity which obliged schools and families to suspend expenses considered non-fundamental;
- The increase of bureaucracy in schools tend to discourage teachers to organise activities outside schools;
- The availability in the geopark of monitors that lead educational activities;
- The offer of lifelong teachers training which is responsible for the increase of the number of involved teachers in certain years.

In addition, it is obvious that covid-19 pandemic has caused a major disruption on Naturtejo's educational activities (2020/21 school year). However, while the in-person activities for students have been suspended since March 2020, it was possible to offer some online activities addressed to teachers, which explains the increased number in 2020/2021.

The number of foreign students and teachers involved in the educational programmes follows the same general trend, in comparison with national students and teachers but obviously with less expression. Most foreign students and teachers came from Spain and USA.

Final Considerations

The establishment of geoparks has created an excellent opportunity to develop nature-based environmental education. Due to the fact that education is one of the geoparks' pillars, the number and quality of educational programmes focused on nature and environmental topics offered by geoparks has increased significantly in many countries.

In Portugal, Naturtejo UGGp has started a "revolution" in Portuguese schools 14 years ago. The educational programmes offered by the geopark were very well received by teachers that were eager to have new tools to improve their teaching. For this very good acceptance contributes the close relation between national curriculum topics and the proposed educational programmes.

In spite the success of Naturtejo UGGp concerning formal education, there are still several challenges that are probably similar to many other UGGp:

- To improve the evaluation procedure regarding activities addressed to students (e.g. setup of online forms to simplify the data analysis);
- To increase the number and diversity of themes;
- To publicize the educative programmes more effectively;
- To increase the number of students involved in activities;
- To promote greater opportunities for immersion and contact with nature to help students to reconnect with it;
- To continue to offer teacher training focused from kindergarten to high school;
- To promote more annual educational projects with schools inside the geopark;
- To create itinerant exhibitions for schools;
- To create the "Schools of Naturtejo Geopark Network";
- To increase the number of monitors and the training of guides from private companies that would like to offer educational activities;
- To improve and translate the educational microsite to English;
- To establish partnerships in order to develop an education centre where the educational resources can be stored and lab/field activities/workshops can be organized with students and teachers.

This work was focused on the Naturtejo UGGp strategy towards formal education but it should be emphasized that this geopark is also deeply engaged on the promotion of activities and resources about environmental education for sustainability addressed to general public. It is expected that all this combined educational effort will contribute to a necessary change of minds of the society and to create more responsible citizens with basic knowledge to allow them face the environmental challenges coming ahead.

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Part IV
Environmental Education and Nature-Based Solutions

Chapter 18
Green Roof and Walls Technology Standardization and Market Across Europe

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Abstract Our climate is being particularly challenged by different anthropogenic influences that amplify the negative impacts of climate change. The rising temperatures and the extreme weather events (heat, drought, storms), as well as changes in precipitation patterns, put pressure on ecosystems and urban population. Therefore, Nature-Based Solutions (NBS) on buildings have gained ground in recent years due to their growing importance. As a result, the European Commission adopted the Renovation Wave initiative as part of the European Green Deal to support the capacity of green infrastructures. The study aims to show the strong economic potential of the green market using the examples of Germany, Austria, and the Czech Republic. These research initiatives highlight the importance of market data as a basis for decision-makers. Various relevant framework strategies have been developed to aim towards a more sustainable, resource and energy efficient building sector. According to the green market studies, a dynamic growth is expected for the next years due to rising awareness for the need of climate change adaption measures and investments

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in NBS. These will be triggered by pro-active strategies of cities who take greening technologies already strongly into account. The successfully implementation of NBS in future requires know-how and constant training and education to recognize innovations and potentials and represent the basis for decision making to environmental issues. Regulations and funding schemes are evolving quickly from these strategies and will push the innovation within the greening sector forward.

Keywords Green infrastructure · Nature based solutions · Natural cooling · Re-naturing cities · Biodiversity · Climate change adaptation · Ecosystem services · Innovation · Green market

Introduction

The climate is being particularly challenged by different anthropogenic influences that amplify the natural greenhouse gas effect while steadily increasing CO_2 levels and global temperature. Furthermore, global population is constantly growing and the associated increase in energy consumption and resource-intensive land use, as well as economic processes based on fossil fuel are continuously impacting the climate and temperature balance [1]. Climate change is often associated to extreme weather events (heat, drought, and storms), as well as changes in precipitation patterns [2]. Furthermore, climate change negatively affects ecosystems and biodiversity and can lead to the loss of habitats and the spread of invasive animal and plant species [2].

Particularly in densely built-up areas the consequences of climate change are impacting the quality of life due to heat islands, the lack of green space and urban flooding related to stormwater events. Therefore, Nature-Based Solutions (NBS) and especially greening buildings have gained a lot of traction in recent years. The benefits of greening buildings have already been demonstrated in numerous studies and many cities are already making use of subsidies and regulatory frameworks to stimulate the uptake of these types of NBS not only on public but also on private properties [2].

The International Union for Conservation of Nature (IUCN) defines [3] NBS as: "Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." The definition of the European Commission reads as follows: "Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions." [4].

Greening buildings provide diverse ecosystem services for humans while increase biodiversity. NBS are a very effective adaptation strategy to keep cities and settlements worth living in due to their wide range of positive effects [5] and possible innovative solutions to make cities greener. Some benefits of green roofs and walls can be summarized as [1, 2, 6]:

- Cooling effects through evapotranspiration of the plants [7].
- Augmenting the existing thermal insulation of the building and saving heating and cooling costs [8–10].
- Increasing the lifespan of the insulation of the building skin as a puffer [11].
- Creating habitats for flora and fauna, thereby increasing biodiversity in urban environments. [12].
- Health and Wellbeing- satisfying the human need for green spaces in living environments. It reduces stress, symptoms of sickness, increase immune system activity, relaxes the body and can even increase motivation [13–15].
- Reducing urban flood events by storing rainwater [16]
- Reducing noise and air pollution. Green spaces increase the physical and health-related comfort by binding air pollutants, CO_2, reducing noise pollution and cooling the surrounding environment [17].

Since green roofs and walls offer this wide range of different measurable benefits, they are considered an important element of the Urban Green Infrastructure. In order to support these potentials, the European Commission adopted the Renovation Wave initiative as part of the European Green Deal [2]. This action plan aims to take advantage of the renovation process and enhance the life in urban areas by making buildings more resilient and support their circularity in terms of energy, waste, and emissions. Several cities in Europe already started to tackle the issue of the existing building stock and try to find proper approaches to ensure that building greening is not only installed on new developments but on older ones too. This underlines the need for a strong cooperation and interaction not only on a national level and among different cities but especially on an international basis. The European Federation of Green Roof and Wall Associations (EFB) represents the umbrella organization of building greening associations across Europe who are dedicated to the issue of quality assurance, creation of guidelines and handbooks and the development and establishment of standards, market research and supporting Green Roofs and Walls on European level. The non-for-profit organization was established in 1997 and represents Small to Medium Enterprises and their employees, dealing with manufacturing, supplying and construction of greening buildings as well as public bodies and research institutions. The EFB cooperates with other green sector organizations (see also the SOGREEN Initiative (1)) in order to strengthen exchange and joint approaches for different green infrastructure technologies.

The following Chapters give insights into the current market research initiatives of the EFB members, knowledge about the European green roof and wall industries' as well as the nature and behavior of the different markets in comparison. In particularly chosen numbers and sizes show the value of NBS which forms the basis to encourage education of our environment, future investments and uptake.

(1) The SoGreen movement intends to unite global stakeholders in the greening sector under an umbrella organisation to empower the collaboration among

different industries in this field (ELCA—European Landscape Construction Association, IFLA—International Federation of Landscape Architects, IOB—International Organization for natural bathing waters, World Urban Parks Europe, ENA—European nurseries Association, EILO—European Interior Landscaping Organisation and EFB.

State of the Art and Standardization

History of Greening Building

Regardless of the climate conditions, greening buildings have a long history for different use either to cool or to insulate dwellings. The Hanging Gardens of Babylon, first appeared 600 BC, are an early appearance of a building with green terraces, used as botanical garden [18].

The first designed model of an extensive green roof was exhibited at the Expo in Paris in 1867 [18]. Throughout the twentieth century the modern way of architecture implemented also concreted living roofs. Architects like Le Corbusier, Alvar Aalto Frank Lyold started to design outdoor spaces on terrasses and roofs [18]. Le Corbusier promoted flat roofs for all residential houses to gain outdoor living space on terrasses and roofs for residents. The idea was to modern up the way of living. The building should have terrasses on every floor to detach the grounded green space up to the garden roofs [19]. The usage of flat roofs started from just having outdoor space for fresh air, sunbathing and some sport activities to having a fully intensive garden with bushes, trees and local food and energy production. Within the industrial era (late twentieth century) the concept of green roof experienced an industrial development especially in Germany. Old German sand roofs show the innovation of this time of mixed gravel and sand with tar for a non-inflammable green roof [18]. In St. Gallen/Switzerland a green roof from the 1900s provides seven different orchid species [20]. Further discovery about orchids on a solar green roof of an office building were made in 2021 in London [21].

Architect Hundertwasser/Austria is nowadays well known for his design to implement the maximum of green infrastructure to the building [22]. The idea to cool down the building and provide shade by using climbers is over 2000 years old. In Central Europe historical buildings such as castles and villages were common to be covered by vine, ivy and climbing roses [22]. In many print media you can follow the gaining popularity about greening buildings within the industrialization [19, 22]. As the interest grew, the research and development has gone along the development of the technology and its requirements over the years. With the expansion urban development, caused by the exponentially growing population, cities were facing several challenges (noise, pollution, etc.). To include all these challenges software tools and methodologies based on expert systems micro-climate simulations have been developed to improve the implementation NBS into the planning process. It helps to see what impact what kind of NBS has on the micro-climate (e.g., GREENPASS®).

Therefore, planned projects become measurable and comparable to find the best NBS implementation project.

Besides that, more and more community oriented and open for public green roof farms are popping up (e.g., Brooklyn Grange) [23]. Over the last years the roof became a place for growing and harvesting locally. Beside vegetables and fruits in many cities you can find beehives on roofs. The pandemic has boosted the demand of closely green spaces and food security [24, 25]. Having a look into local, sustainable methods of producing own food and food for others, green roofs turned also into a working space for beekeepers in cities. It is part to not just visit these best practice projects but also participate and learn from these projects and rise a better understanding of the involvement in the urban environment. By educating and promoting about NBS, the awareness and understanding of urban ecosystem will grow. On the other hand, also industrialized approaches like Urban Farming and Vertical Farming inside buildings and on building skins to ensure food security and counteract sealing and massive agricultural land use are getting into the spotlight, pilot projects can be found on a worldwide scope [26].

State of the Art Technologies

Land is limited, so it is even more important to create optimized multiple uses on the building and combine them with renewable and sustainable infrastructure [7].

Green roofs are defined as building greening using a vegetation layer. All forms of green roofs consist at least of vegetation, substrate or substrate substitution, filter and drainage layer. Depending on the substrate height green roofs are placed in two different types: extensive or intensive. This distinction depends on the design of the vegetation layer, which depends among others on the height of the substrate. Extensive green roofs have an overall low installation height and weight, require low maintenance and have succulents, moos, herbs and grass as the dominating vegetation (Fig. 18.1). Intensive roofs have a deeper substrate layer and need a good structure capacity, require higher maintenance because of a higher vegetation, like ornamental lawn, demanding shrubs, bushes and trees (Fig. 18.2) [27, 28].

Depending on what functionality the green roofs should fulfill there are different design possibilities. If the aim it to enhance biodiversity, one can implement sand, gravel, death wood and water sites. For better stormwater management green roofs can also be built as retention systems. Furthermore, green roofs can also be used to produce energy, so called solar green roofs or biosolar roofs (see Fig. 18.3 and 18.4). Integrated mounting solutions for Photovoltaic renewable energy with a green roof where the substrate and vegetation provide the ballasted installation mechanism [29–31].

The combination of green roofs with photovoltaics has following benefits [32–36]:

- increased efficiency of the solar system through evaporative cooling: the cooling effect of the green roof can help to mitigate the heating of the Photovoltaic modules

Fig. 18.1 Extensive green roofs have succulents, moos, herbs and grass ©GRÜNSTATTGRAU

Fig. 18.2 An intensive green roof can be designed with trees ©DAM.architekti

Fig. 18.3 The combination of green roof and energy production yield synergies ©GRÜNSTATTGRAU

- increase in biodiversity due to different site conditions on the roof: the combination creates different light-shadow and humidity conditions
- protection of the waterproof layer from thermal and mechanical stress. In the case of load-bearing systems for the combination of green roofs and solar systems, roof penetrations or other interventions in the roof sealing and building structure are not necessary.
- point loads can be avoided because of the uniform load distribution of the substrate

Green walls can be implemented in three different categories (as well as mixed forms) [37]:

- ground-based with self-climbers or with climbing plants and climbing trellis
- trough-based
- wall-bound

Depending on the climbing strategy of each plant and the nature of their adhesion ability, different climbing supports—if needed- can be used. Greenwall-bound systems nearly always have an automatized irrigation and nutrient supply system and offer many design options. They are installed on the facade with an air circulation system between the existing facade and the green wall (back ventilation). The system provides insulation to the building [37, 38].

Fig. 18.4 Solargreen Roofs increases biodiveristy through differnt shading areas © Bundesverband GebäudeGrün e. V. (BuGG)

Standardizations

The relevant framework strategies for future development of the building sector towards more sustainability, resource and energy efficient at European and national level (EU Buildings Directive, OIB Directive), as well as national as European wide certifications for buildings (e.g., klimaaktiv, LEED) demand to increase the use of greening buildings.

Therefore, standards and guidelines are playing an important role to transfer knowledge, educate and specify minimum standards in the construction sector. There are several existing standards and guidelines like FLL [28, 39], ÖNORM [38, 40], SIA [41, 42], UNI [43, 44], SM 3700:2017 [45], The Czech Standard [46], The Swedish Green Roof handbook [47], Regles Professionelles [48] and The GRO Green Roof Code [49]. Some are just recommendations, while some are legally binding. The focus of each guidelines differs reading on the climate conditions, challenges cities or countries.

In Germany, the guidelines called FLL for green roofs and green walls are not binding but represent the code of practice. Many of the now existing standards and guidelines worldwide have been developed based on the German guidelines. The Swiss standard (SIA) addressed as the first one more nature conservation design issue for green roofs [35]. In Austria the first industry standard for green roofs (ÖNORM L1131) was published in 2010 and is currently revised. The Austrian green roof standard includes criteria of quality and an evaluation scheme for green roof components and systems [27]. The VfB is awarding products which are tested and following the standards to reassures architects and builders to invest into highest quality of Austrian producers. Standardization, assessments and technical sign-off are tools the association is using to ensure the quality of greening projects. The standard for indoor green walls came out in 2013 [40].

The ÖNORM L1136 for green walls (2021) represents the first legally binding industry standard for green walls in Europe. It defines construction methods, maintenance, servicing and care of outdoor vertical greening as well as the application of building materials and plants. Austria has all three technologies of greening building standardized and must be observed in implementation projects.

Besides that, more and more cities all over Europe are publishing local guidelines and handbooks to promote greening building as a part of their strategies for climate change adaptation [2, 50]. These are important instruments which are helping to roll out greening building technologies in a local and optimized quality context, respecting local strategies and benefits needed. Further the request and need of NBS education programs on different levels and to learn from each other is noticeable. Summing up activities and experiences of the implementation process of NBSs in cities will be published as a MOOC (Massive Open Online Course) with global outreach through the H2020 project proGIreg [51].

Innovation and Vision

Greening Buildings is a strongly cross-technological field of innovation that interfaces biology and ecology, construction and building physics, energy and environmental technology as well as environmental engineering. These innovations are related to the scientific fields such as material, social, health and systems. Over the last 20 years intensive research and technological developments in the greening building fields have led to the fact, that an incredible wide range of technical components and systems is currently available on the market but also a broad know-how in vegetation technology [2]. This leads to a wide range of available applications and a growing industry including new jobs. Market researches are able to provide future experts and decision-makers with the know-how it needs for training that enhance environmental education through NBS. The received data can be used for measuring NBS implementation success and its effectiveness in terms of benefits. Furthermore, strategies, subsidies, investment in research and further realizations of NBS projects can be relied on this data.

At the current European Research and Innovation agenda, NBS just like green roofs are addressed [35]. The EU funds a large number of innovation and research project to focus on climate change adaption, where the gained knowledge and defined implementation processes are aimed to be shared cross-sectoral and cross-border.

For further development of innovations, the fields of monitoring and maintenance are becoming very significant. These can be made simpler, more resource-efficient and more cost-effective, as they still very often represent a barrier. Future innovation fields are also in the sector of business model developments with digital media along the entire value chain ‘construction’ [2].

To connect these different sectors, the H2020 project METABUILDING (2020–2023) addresses to set up a cross-sectoral and cross-border innovation ecosystem for European SMEs. The METABUILDING innovation ecosystem brings together stakeholders from construction and emerging industrial sectors; recycling & circularity, additive manufacturing, NBS and digital industry. The METABUILDING Platform aims to facilitate collaboration between new partners and experienced experts to further innovation [52].

Green Roof and Wall Markets

Up to now, the documentation and the development of the greening sector was based on estimations due to the varying policy activities and incentives among the European countries and very basic yearly data collection by some exemplar industry associations [50].

In order to take account of the growing importance of green buildings in the urban environment and fill the gap of missing industry data in the future, several European countries and their national associations embedded in the EFB started analyzing and investigating the current status, trends and growth opportunities in the field of building greening. Summarized in the national “Green Market Report” a comprehensive data collection involving key stakeholder groups in the building greening sector is conducted [2]. It offers an extensive overview of the available green building technologies and documents the market development based on the facts and figures collected. With the growth and future projections derived from this and a detailed presentation of the companies active in the greening value chain, an informative business card of the greening industry has been created for Austria, a success story that now other countries are following (e.g., Czech Republic). First results have shown the huge potential of this sector for direct and indirect new and future-proof jobs. Therefore, a wide range of measures in the field of green infrastructure would set in motion a permanently effective job and economic engine. Research and innovation make a significant contribution here. Technical solutions are further developed in a targeted manner and existing potential is tapped and made ready for the market in cooperation with technology manufacturers and public and private stakeholders [2].

However, the actual value in terms of employment and the contribution from an economic perspective is not widely known yet. Therefore, there is a need of a comprehensive European market report to highlight the importance of the building greening sector for significant policy agendas including climate adaptation, economic growth, strengthening of the biodiversity in Europe as well as improving the health and well-being of urban citizens. By demonstrating the environmental benefits of the building greening industry, the European Commission, national governments, the regions and cities can be supported in the development of more advanced and innovative policies and processes to again further encourage and enhance the industry and its value itself.

Furthermore, strategies to incentivize the development of the building greening market are needed. Innovation activities, alliances, platforms, subsides and national as well as international programs are slowly emerging. Among these are e.g. alliances (https://worldgreeninfrastructurenetwork.org/ or https://worldgreeninfrastructurenetwork.org/eu-chapter/ [(2)]*by WORLD GREEN INFRASTRUCTURE NETWORK*) that actively exchange with the European Commission on green infrastructures and NBS and promote the global incorporation of urban green infrastructure, platforms (e.g. *Nature Based Enterprise Platform* https://www.naturebasedenterprise.eu/ or METABUILDING https://www.metabuilding.com/) that connects organizations and stakeholders in the field to facilitate the collaboration and further innovation, national subsidies and financial support when implementing green walls or roofs, etc.

[(2)]The EU Chapter comprises the European part of a collaborative network of national and regional industry associations that aim to raise awareness of the benefits of greening building, especially among decision-makers at EU level.

Green Roof and Wall Market in the Czech Republic

The History and Development of the Green Infrastructure Market

Presumably the oldest green roof in the Czech territory dates back to 1863 and can be found on a chateau in Lipník nad Bečvou but the first modern green roofs in the Czech Republic appeared towards the end of millennium [53]. The fall of communism fostered international mobility and the transfer of knowledge, thus enabling the development of new market segments. However, it was not until 2000–2010 that the first large green roofs projects emerged. A famous project of an intensive rooftop garden on top of ČSOB (Czechoslovak trade bank) in Prague comes from this period and with its 4500 m^2 of green areas is still one of the largest intensive rooftop gardens in the country, inspiring many others. Green roofs were often being made using ad hoc substrate mixtures and improvised lower layers due to low awareness of what elements constituted a functional vegetation build up. Specialized foreign materials were costly for the purchasing power in the market, thus green roofs were placed in the segment of luxurious goods.

The level of awareness of specialized green roof technologies began to rise owing to the engagement of foreign, predominantly German, producers of system green roof solutions. After 2010, progressively-minded architects were including green roofs in their projects, yet the main driver was still the aesthetic rather than function. In 2013, the Czech Green Roof Association (ZeS) was founded under the Czech Landscape Gardening Association (SZÚZ) with the aim of raising awareness, promoting green roof benefits and publishing expert documents on the topic. The Association, which immediately after its founding became a member of the EFB, brought together companies with experience in green roof installation as well as producers of green roof components and other experts.

Around 2015, record heatwaves and other climate anomalies were becoming more frequent and impacted the whole society, therefore the phenomenon of climate change was being taken more seriously by the general public and institutions. Green roofs were increasingly viewed as one of the solutions to mitigate the impacts of climate change in cities. The National Climate Adaptation Strategy [54] and its Action Plan [55] were adopted at this time and mentioned the potential of green roofs for urban areas with regard to mitigation of rainwater runoff, lowering temperature related risks, ensuring a stable and functional system of urban greenery and the recovery of ecosystems and adaptation to climate change. The Action Plan then stimulated the inclusion of green roofs into a nation-wide subsidy program called New Green Savings (Nová zelená úsporám), the first green roof subsidy program in the country providing 500 CZK (approximately 20 EUR) per square meter of green roof [56]. Furthermore, since 2018 green roofs have been subsidized on public buildings (Velká Dešťovka program) [57] and some municipalities have launched municipal subsidy programs for green roofs (Brno [58], Prague 6 [59], Ústí nad Orlicí) and walls (Ústí nad Orlicí [60]).

The Development of the Green Infrastructure Market

The market development of the green roof industry has been recorded by ZeS since its founding and can be seen in Fig. 18.5. The figures are derived from quantities of roof substrate, the key component of any green roof, and the average build up height. Based on most recent data by ZeS [61], it is estimated that there were around 1.6

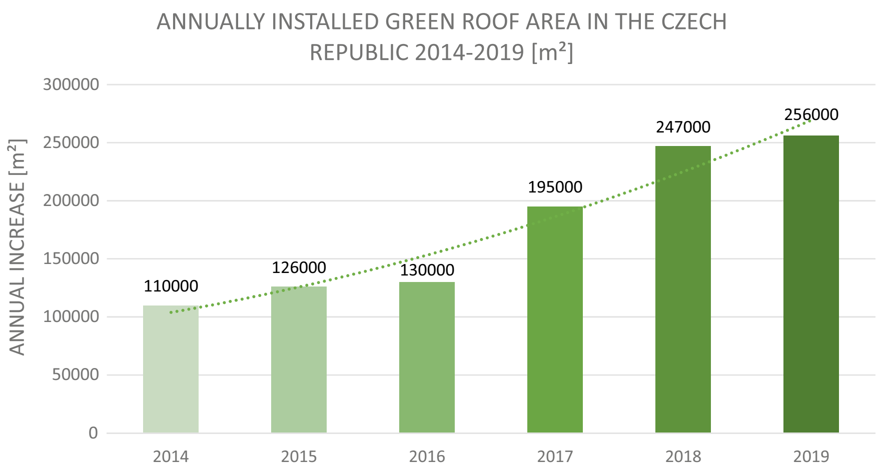

Fig. 18.5 Annually installed area of green roofs has been steadily increasing in the Czech Republic [61]

million m^2 of green roofs in the Czech Republic as of 2019. The majority of new green roofs were being built as extensive (179 000 m^2, 70%) while intensive were less frequent (77 000 m^2, 30%). The Czech green roof sector generated a turnover of 18 m EUR and employed around 400 people [62].

In the volume of installed green roofs, they dominate on new buildings reference. This is mainly due to the fact that the greening of the newly designed structure is technically easier than the greening of existing structures. Investors of green roofs are most often private individuals or companies, but there is also a notable increase in public procurement. While in 2018 the ratio of private to public procurement was 7:1, in 2019 the ratio shifted to 6:1. Among private contracts, family and apartment houses significantly dominate, among public contracts the most frequent are schools, kindergardens, hospitals, municipality buildings, libraries etc. [61].

Companies dealing with projects and implementations of green roofs are most often small entrepreneurs and small and medium-sized companies. Manufacturers of materials for green roofs are represented by a variety of companies of different sizes: small specialized entrepreneurs, small and medium-sized production and multinational suppliers from abroad. Research in the field of green roofs is done namely by the following institutions: Brno University of Technology, University Centre for Energy Efficient Buildings at the Czech Technical University in Prague, Jan Evangelista Purkyně University in Ústí nad Labem, Partnership Foundation and IREAS.

Concerning the regulatory environment, one of the biggest drivers for the installation of green roofs is rainwater management. According to provisions in the Water Act [62], builders are required to manage rainwater on their plot with regard to the principles further set out in the Construction Act [63]. The enacted hierarchy of rainwater management is as follows: infiltration, retention and regulated discharge to rainwater sewer, regulated discharge into single sewer. A further driver for the use of green roofs is the obligation of properties in public and enterprise ownership to pay for the rainwater runoff according to the Act on water mains and sewers [64]. Since green roofs can significantly decrease runoff quantities, the rainwater fee can also be decreased, thus reducing the payback period of the green roof installation costs for the builder. The hierarchy of rainwater management and rainwater fee conditions are expected to be amended in the near future and thus be even more favorable to green roofs and other ecological water management strategies.

Outdoor green (living) walls are one of the emerging trends in architecture, however, their uptake is slowed down by the availability of reliable technologies to enable their long-term functionality in the local climate conditions. The use of climbing plants in urban greening also generates interest, yet its potential is also higher than the current use. A strong trend is the greening of visible rooftop areas, and if possible, the availability of such areas for occasional stays. Green roofs continue to be important topics in brownfield renovation [65] and sustainable construction and there is a distinct interest in the combination of green roofs and sustainable energy sources on rooftops.

Green Roof and Wall Market in Germany

Green Roof Market

A yearly survey of the total market of newly greened roofs is conducted by the Fachvereinigung Bauwerksbegrünung e.V. (FBB), one of the two predecessor associations of the Bundesverband GebäudeGrün e.V. (BuGG), since 2008. The BuGG has been continuing this analysis since 2018. For this purpose, substrate manufacturers and suppliers were asked about the quantities supplied in Germany of the following substrate types: extensive substrate (single and multi-layer), intensive substrate (single and multi-layer).

With the help of the determined delivery quantities and via fixed assumptions on the installation heights of extensive and intensive green roofs in single and multi-layer construction, the newly greened roof areas could be calculated approximately, but also differentiated into extensive, intensive, single and multi-layer. In order to test and confirm the measurement method as well as the conversion factor used, an additional survey was conducted among manufacturers and suppliers of protective layers for 2018. The values obtained from this were able to confirm the results of the substrate survey. The most important results of the BuGG Green Roof Substrate Survey are:

– In Germany, a total of 7,217,720 m^2 of green roofs were newly added in 2019,
– Of these, 6,024,421 m^2 were extensive green roofs (83.5%),
– While 1,193,299 m^2 were intensive green roofs (16.5%) [66].

The determined total green roof area includes all types of green roofs; the method currently does not allow for differentiating between flat and pitched roofs or underground garages or even building types. It can be assumed that, in addition to the companies participating in the annual surveys, there are other, mostly regionally active substrate manufacturers whose delivery quantities are not included, which is also the case for "conventionally" (gravel and soil fill) designed underground garage green roofs. Although this was compensated by a correction factor, it can be assumed that the total area of annually greened roofs is likely to be even higher than the values determined by the BuGG surveys [66].

The approximately 7,200,000 m^2 of new green roof area added in 2019 sounds like a lot at first, but it represents only about 9% of the assumed 80,000,000 m^2 of total new flat roof area. This means that in 2019, around 91% of the flat roof area still remained without greening [66].

The large remaining potential of greenable roof area as well as the previously mentioned figures are graphically depicted in Fig. 18.6.

Since the method of the BuGG Green Roof Substrate Survey and the companies involved have remained unchanged over the years (since 2008), the figures can be compared well with each other, developments can be shown and trends can be derived.

The BuGG was able to determine the following market figures from this:

– From 2008 to 2019, a total of 58,341,198 m^2 of green roof area was installed.

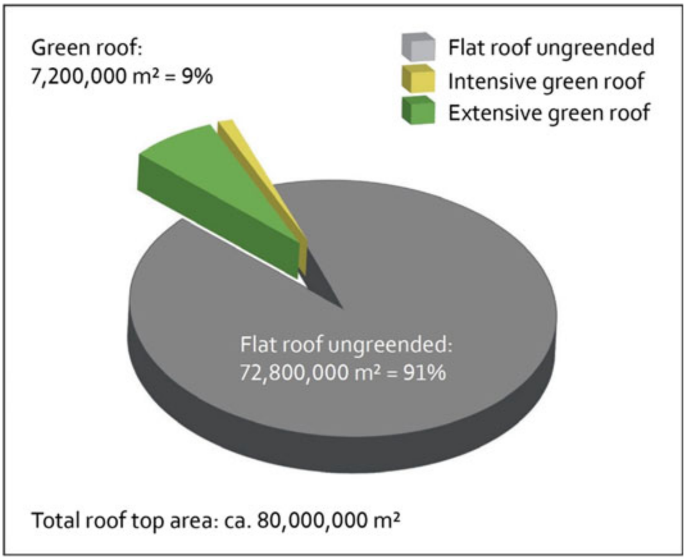

Fig. 18.6 Green roofs added in 2019 in relation to the total newly created flat roof area [67]

- Of the total amount, 49,106,236 m^2 of roof area was extensively greened, which corresponds to 84.2%.
- Of the total amount, 9,234,962 m^2 of roof area was intensively greened, which equals to 15.8%.
- The green roof market is growing at an average annual rate of about 7%.
- The green roof market has grown by 100% from 2008 to 2019.
- The trend moves towards intensive green roofs (roof gardens) and thus (predominantly) green roofs that can be walked on and used. While the share of intensive green roofs was still 11.4% in 2008 (extensive: 88.6%), it has risen significantly until 2019 with 16.5% (extensive: 83.5%).
- The average annual growth of intensive green roofs was higher than that of the extensive green roofs. Over the past 12 years, extensive green roofs have grown by an annual average of 6.6%, while intensive green roofs have grown by an average of 10.8%.
- The trend toward extensive greening in multiple layers is even more pronounced: while the ratio of single to multiple layers was 47:53 in 2008, it was 28:72 in 2019.
- Single-layer construction methods play a subordinate role in intensive greening [66].

So far, only few German cities have taken and published inventories of their existing green roofs throughout the urban area. The BuGG has collected the inventory figures of green roofs of different cities and compared these data with different variants. Such information was available from 15 cities. In variant 2, the sum of the determined green roof areas per city is put in relation to the respective number of inhabitants (IN). This then results in the green roof square meter value per inhabitant ("Green Roof Index") (See Table 18.1). On average, the Green Goof Index of the 15 cities is 1.2 m^2 per inhabitant. The current leader, Stuttgart, has a Green Roof Index of 4.1 m^2/IN, which means that on average there are 4.1 m^2 of green roof for every inhabitant [66].

The appealing thing about this approach is that even smaller cities can compete for the "championship", since relative values are used. The ranking is therefore independent of the size of the city. It should not go unmentioned that the values of the individual cities can only be compared to a limited extent, as both the methods and the times at which the data were collected differ in some cases. With the "BuGG Greenroof National League" there are for the first time well-founded values for the Greenroof Index in a city comparison, in order to provide a key figure for politics and urban planning. Cities can also now better rank themselves and their green roof activities in comparison to other cities. Ideally, cities should take stock of their green roofs at regular intervals, for example to check the effects of direct and indirect support measures that have been introduced.

Table 18.1 Green roof index in German cities [67]

Rating	City	Year of data collection	Inhabitants	Green roofs without underground car parks [m^2]	"Green Roof Index" (m^2 green roof/ inhabitant)
1	Stuttgart	2017	632,742	2,593,670	4.1
2	Munich	2016	1,464,301	3,148,043	2.1
3	Frankfurt am Main	2015	732,688	1,436,371	2.0
4	Nuremberg	2015/2008	40,395	59,450	1.5
5	Düsseldorf	2018	642,304	921,000	1.4
6	Hannover	2016	532,864	633,076	1.2
7	Osnabrück	2017	164,374	157,000	1.0
8	Nürnberg	2016	511,628	450,000	0.9
9	Berlin	2016	3,574,830	2,969,396	0.8
10	Braunschweig	2008/2010	246,012	186,536	0.8
11	Straubing*	2019/2020	48,110	33,617	0.7
12	Karlsruhe	2015	300,051	177,546	0.6
13	Ottobrunn	2016	21,000	9,500	0.5
14	Dresden	2018	560,641	236,960	0.4
15	Mannheim	2014	296,690	22,000	0.1
				Mean	**1.2**

* Green roofs on properties with rainwater infiltration were not taken into account

Germany has a long green roof tradition. Roofs have been professionally greened since the mid-1970s [66]. The Bundesverband GebäudeGrün e.V. assumes, based on the available figures from the BuGG Green Roof National League, the BuGG surveys and the extrapolation derived from those, that there is a total of 100,000,000 m^2 to 120,000,000 m^2 of green roof areas in Germany [66].

Facade Greening Market

It is more difficult to determine the area size of the facade areas greened in 2019 than for the greened roof areas. The data for wall-bound facade greening can be determined quite easily, since the system solutions are only sold and installed for greening and in square metres.

For ground-bound facade greening. System suppliers of climbing aids are often unable to clearly identify whether the products sold are used for greening purposes or which spaces are actually greened. Depending on the spacing between adjacent linear climbing aids, the greening areas vary in size. One running metre of linear climbing aid does not necessarily equal one square metre of facade greening. An exact determination of newly planted areas of ground-based facade greening with self-climbing plants (direct greening without climbing aids) is not possible for various reasons. Among other things, the distribution channels of plants used in greening facades are diverse. Additionally, both professionals and laymen are implementing ground-based facade greening. Lastly, it is difficult to determine the area that might be greened in the coming years [67].

This needs to be kept in mind when looking at the data determined and presented below on the facade areas greened in 2019. The BuGG asked its members, who offer product and system solutions for facade greening, about greened areas in 2019. The total area of both ground- and wall-bound facade greening were surveyed, although in the case of ground-bound facade greening, only the areas with climbing aids were considered.

- According to the survey, a total of about 20,000–55,000 m^2 of facade area was newly greened with wall-bound and ground-bound facade greening (with climbing aids) in 2019.
- Of this, wall-bound facade greening takes up an area size of approximately 5,000 m^2.
- The surveyed BuGG members assume a ratio of wall-bound facade greening to ground-bound facade greening with climbing aids of 1:3 to 1:10. This results in a total facade area planted with climbing aids of 15,000–50,000 m^2 [67].

As stated above, no figures could be determined for the area sizes of ground-based self-climbers. The BuGG assumes an approximate range of 20,000 - 80,000 m^2.

Municipal Subsidies and the BuGG City Survey

At the municipal level, the implementation of green roofs and facades can be promoted through various instruments that differ in their scope of action, their binding nature, and their financial cost to the city. The BuGG City Surveys from 2010 to 2019/2020 serve as the data basis [68]. For the "BuGG-Market Report on Building Greening 2020" [66] the survey data were supplemented by BuGG research and marked to provide a comprehensive picture of the financial support of green roofs and facades in Germany. While FBB and NABU included all German cities with more than 10,000 inhabitants in the survey until 2016/2017, BuGG narrowed the survey in 2019 to all German cities with more than 20,000 inhabitants [68]. Within a questionnaire, the various funding instruments (except for municipal bylaws) were queried both digitally and analogously among the cities contacted and the responses received were subsequently analysed. The main findings are as follows:

Funding programs (direct financial subsidies):

- The proportion of cities offering direct grants for green roofs has increased (2010: 6%, 2019: 19%).
- Among cities with more than 50,000 inhabitants, 49 cities, or about 26%, already provide financial grants for green roofs.
- The range of maximum subsidies extends from €10 to €100/m^2 and €500 to €100,000/project.
- A similar increase can be seen for direct subsidies for green facades (2010: 6%, 2019: 17%).
- Among cities with more than 50,000 inhabitants, 45 cities and thus approx. 24% already provide financial subsidies for facade greening.
- In percentage terms, the funding limit varies between 20 and 90% of eligible costs. For a majority of the cities, the maximum subsidy is 50%.

Development plan

- More and more cities are making both green roofs (2010: 34%, 2019: 67%) and green facades (2010: 32%, 2019: 45%) mandatory in development plans.
- The share of cities with more than 50,000 inhabitants with stipulations in their development plans is 73% (green roofs) and 41% (green facades).

Ecopoints for green roofs

- The proportion of cities awarding eco-points for green roofs under the impact compensation scheme rose from 9% (2010) to 21% (2019).
- For cities with over 50,000 inhabitants, the share is already 24%.

Reduction in fees for split wastewater charges

- The proportion of cities promoting green roofs through a fee reduction has remained at a similar level since 2012 (2012: 49%, 2014: 53%, 2016/2017: 54%, 2019: 49%).

- For cities with more than 50,000 inhabitants, the share is now very high at 72%, according to our own research.
- Among different cities, both the precipitation water fee per year (in 2019 on average €0.81/m^2) and maximum fee reduction for a green roof (0% to 100%) vary.
- The average maximum fee reduction for a green roof in 2019 was 59% or €0.48/m^2 [66].

Summary and Outlook

Through the comprehensive overview on the German green building market provided by the "BuGG-Market Report on Building Greening 2020" it can be seen that building greening is no longer a "niche" product. The building greening market has not only higher levels of awareness but is also reflected in a large number of projects. The green building market is growing and is a future market with great potential:

- Only about 9% of newly created flat roofs are currently greened.
- The green building sector, including its related trades, already provides thousands ofthousands of jobs—and the trend is rising in line with this growth!
- Green roofs and facades are an important adaptation measure to climate change: rainwater management (flood protection) and heat prevention (evaporative cooling), plus species protection/biodiversity.
- Improvement of the urban climate by binding dust and CO2 and thus, for example, an important contribution to preventing driving bans.
- Additional usable and recreational space for people: the in-house roof garden as a crisis-proof leisure, recreational and cultivation area. To date, only about 17% of green roofs are intensively planted and used by people [66].

Green Roof and Wall Market in Austria

Green Market Report Austria—Motivation and Methodology

Connecting plants with building envelopes as an architectural and functional measure is well known in European building history. Modern greening technologies have been applied in Austria since the mid 1980ies [69]. Over the course of the last four decades a well-established sector has emerged, with the Austrian Association of Green Buildings and Walls (VfB), which was founded in 1991, as a main driver for technological and market development. With the foundation of the Innovation laboratory GRUENSTATTGRAU—owned by the VfB and subsided by Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology—in 2017, another boost in the development of the sector was generated.

In 2018—based on a joint effort with the EFB—a major market research initiative was launched, to collect, analyze and publish key market figures and to describe the development of the Austrian greening industry. Based on the facts and figures generated for the first Austrian Green Market Report [2], forecasts and growth scenarios have been provided to decision makers in the sector and to policymakers who are in charge to create a legal and financial framework for the further development of urban green infrastructure that is crucial to live quality in midst of the ongoing climate change in the Alpine Region.

The market data was derived from online surveys [2] with all stakeholders of the greening industries´ value chain and with municipalities of Austrian cities with more than 10.000 inhabitants. Market volumes of the green roof, green wall and the indoor green wall market were calculated with the support of the Austrian substrate manufacturer and green roof protective layer provider, the manufacturer of green roof and wall systems and components provider and indoor green wall system manufacturer, as well as project planers and successful tenderer of greening projects. 137 companies and 55 municipalities took part in the on-line surveys. Sensible market data from companies was collected via a notary option included in the questionnaire reference. Thus, the development of the Austrian green building sector between 2014 and 2018 could be solidly described.

The Austrian Greening Sector

The Austrian green roof and walls sector generated a total turnover of 90,5 m EUR in 2018. The average yearly growth rate of the sector between 2014 and 2018 was 9.6% [2].

Ca. 550 companies with 1200 employees are actively engaged in the green building value chain as displayed in Fig. 18.7. Data shows that the number of new market

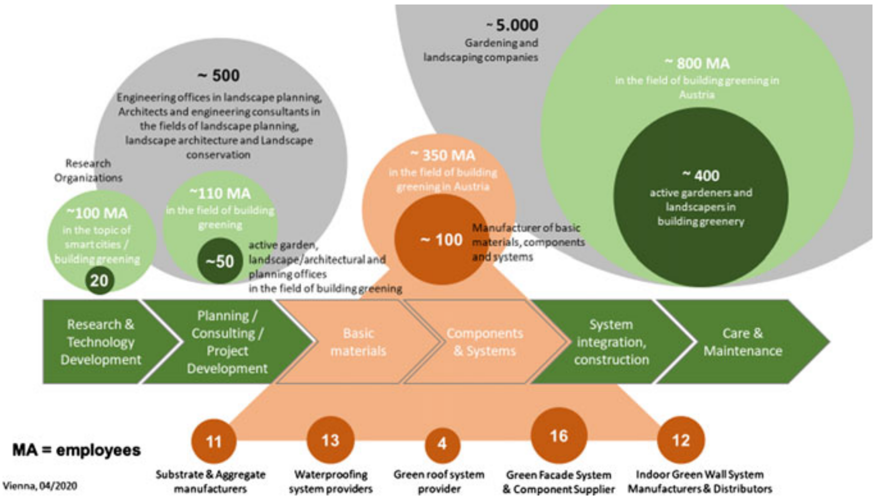

Fig. 18.7 The greening industry value chain in Austria [2]

entrants is on the rise, many of these companies add greening services and products as new business units to their existing business models. 68% out of 50 companies answered that their turnover in the green building sector is less than 50% of their company turnover [2].

The Austrian Green Roof Market

The largest part of the green building market is the green roof market. In 2018 more than 1.050.000 m^2 green roofs were newly installed. The installed volume has grown yearly by 6,7% on average starting from 830.000 m^2 in 2014 [2].

The split between extensive and intensive green roofs was rather consistent over the time period. In 2018 86% of newly installed green roofs were built as extensive roofs whereas 14% were intensive [2].

Although the data shows a significant growth between 2014 and 2018, there is still plenty of potential further possibilities. Only 1 out of 10 flat roofs of new buildings are greened and there is a huge opportunity, when it comes to renovating the existing building stock [2].

One important trend that can be observed is the combination of photovoltaics with green roofs. As Austria is having a clear policy to enhance renewable energy sources, solar green roofs are a perfect combination to harvest energy without additional land use and to benefit from green roof functionalities to strengthen the climate resilience of buildings. The companies in the green roof market are quite optimistic when they were asked about the future market development. 37.5% believe that the market will grow at more than 7.5% on average in the next 3 years whereas 54.5% answered the yearly average growth rate will be between 2.5% and 7.5% [2].

The Facade Greening Market in Austria

The facade greening market is determined by a variety of technologies that reach from ground-bound facade greening with self-climbing plants with or without climbing aids as an inexpensive and well-known form of greening walls to trough-bound solutions and sophisticated wall-bound systems, which makes it difficult to collect the market data in full scale. Based on provided data from system and components provider and interviews with experts in the facade greening market we estimate that in 2018 ca. 40.000 m^2 of green walls were added. Most of newly installed green walls are made with ground-bound technologies whereas wall-bound systems are still in a demonstration phase with few applications [2].

The yearly average growth rate was calculated with 8.88% and the industry expects further growth at a similar pace for the upcoming years [2].

Climate Change Adaption and Greening Technologies in Austrian Cities

The Austrian city study revealed that climate change adaption is seen as a major challenge across all sizes of cities. Two out of three municipalities already have put into action strategic initiatives to dilute negative impacts of climate change. Building up green infrastructure is at the core of these strategies to prevent their cities from urban flooding and growing problems with urban heat island effects [2].

Maintaining existing and planting new city trees is the most common activity (89% and 84% of the responding cities). Measures for water retention (44%) are also frequent measures whereas mandatory green roofs (22%) and walls (4%) in certain areas are less often implemented [2].

A weak point is that only very few municipalities map the green roof and wall inventory of their city. Therefore, it is impossible for most of the cities to document progress in the expansion of urban green infrastructure based on quantitative data [2]. A green roof index ranking as published by BuGG in Germany might also be helpful in Austria, too.

Summary and Outlook

The Austrian greening market has been constantly growing over the last years. Further dynamic growth is expected for the next years due to rising awareness for the need of climate change adaption measures and investments in urban green infrastructures. These investments will be triggered by pro-active strategies of Austrian municipalities who take greening technologies already strongly into account, to ensure urban live quality in the upcoming years. Regulations and funding schemes on local, regional, and national level are evolving quickly from these strategies and will push the Austrian greening sector forward.

At the same time the sector must work consistently to overcome existing barriers like information deficits and low awareness of greening technologies within the real estate sector, and affordable total costs of ownership of green roofs and walls.

Conclusion

With the data of the national green market reports the importance of the greening building sector from environmental as well as economic view can been shown. It forms the basis for policy and decision makers to invest in NBS like green roofs and green walls as a climate change adaption strategy. To enhance environmental education there is a need to provide information and know-how for the industry and public sector. Germany and Austria can be seen as pioneers in the field of greening buildings since they developed and published standards and guidelines that do not only help involved national stakeholders and provide quality assurance, but also support other European countries in developing their own standards. This can be seen in the example of the Czech Republic who took action after climate anomalies in 2015. Soon after, climate adaptation strategies were enforced and subsidies were realized to support the installation of greening building. Through the international exchange these processes were supported.

By implementing greening buildings in our urban city planning residents will reconnect to nature and its benefits. This process requires exchange of know-how (standards, guidelines, etc.) and open access to assure a general understanding for the public as well as quality and sustainability in the planning, constructing and maintenance process for the industry of greening buildings.

With the building of green roofs and walls the general public can experience the impact, values and benefits of a part of nature-based solutions. This way, the environmental education and a responsible treatment of the environment will be enhanced. Furthermore, the rising awareness for the need of climate change adaption is also the motor to collect data from the NBS market. The reports are the basis for decision-makers to invest and monitor the success of urban green infrastructures in the future.

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Chapter 19
How Nature-Based Solutions Can Contribute to Enhance Circularity in Cities

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Abstract Environmental education in different disciplines puts an accent on acquiring specialised knowledge and, while this remains essential, fostering knowledge alone, without links to real life, personal experiences, competencies, and values, is insufficient. Nature-based solutions (NBS) have the potential to be used as an educational framework that requires critical system thinking, a crucial component of truly democratic active citizenship, and raises awareness about global environmental, social, and economic issues. On the basis of NBS-related environmental education materials, we present in this chapter selected case studies that describe education for three main stakeholder groups. Concerning pupils and students, these are examples for schools and higher education, as well as pilot installations from

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Italy, Spain, Slovenia, Portugal, Turkey, and Germany. Different forms of facilities or organisations are included to demonstrate the possibilities of NBS-related education for practitioners. The offers for the general public comprise a mobile exhibition/demonstration unit, a social project and an animation video. Additionally, existing online platforms for knowledge sharing are summarised. The NBS concept has potential to assist the transition from current conventional education paradigms towards to a more critical systemic thinking to foster environmental citizenship as a base for environmental, social-economic, political, economic, and cultural changes on local, national, and global scales.

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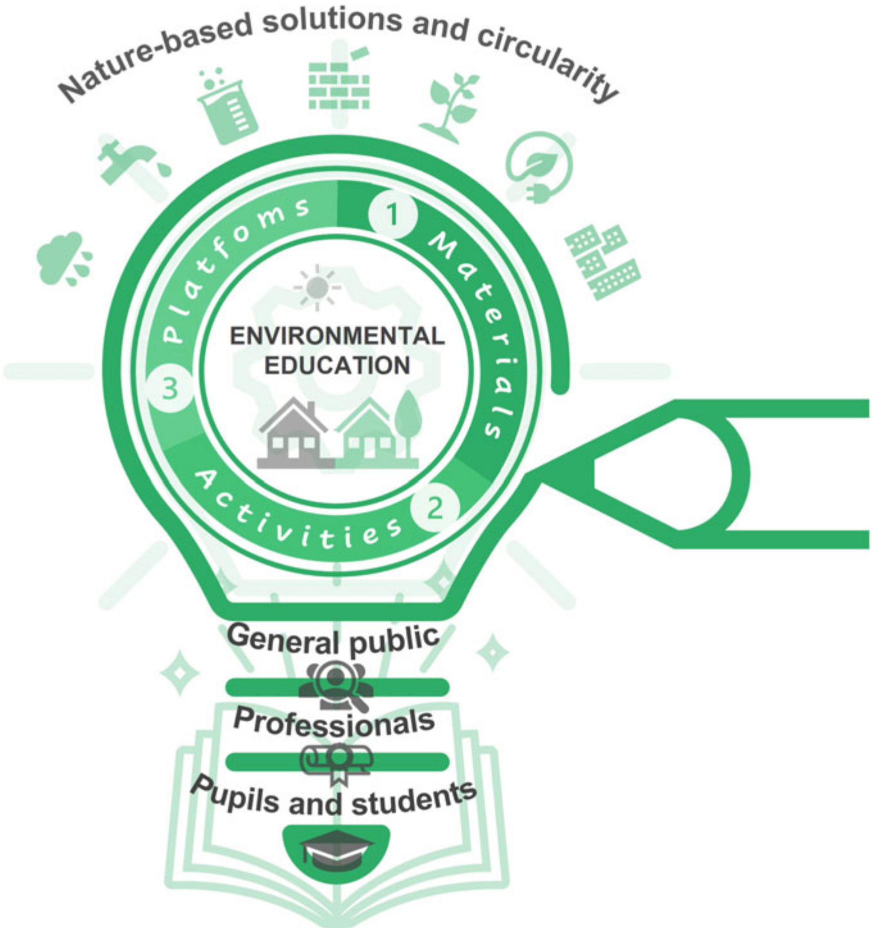
Graphical Abstract



Keywords Nature-based environmental education · Nature-based educational framework · Critical systemic thinking · Urban circularity challenges · Nature school · Outdoor education · Childhood education · Higher education

Introduction

While humanity recognized climate change as its major existential challenge and prepares to battle it, the need to mobilise the entire society for the task is acute. Thus, advances in environmental technologies need to be coupled with a rapid and generalised change in values and attitudes. However, there are still important hurdles to overcome to achieve this goal. One of the most important is the current fragmentation of knowledge production and disciplinary training system. Environmental education still remains highly specialised and predominantly focused on natural sciences, with socio-political and empowerment aspects only marginally included if at all. Moreover, environmental education in different disciplines focusses on acquiring specialised knowledge and, while this remains essential, fostering knowledge alone, without links to real life, personal experiences, competencies, and values, is insufficient [1].

The COST Action CA17133 Circular City investigates how nature-based solutions (NBS) can be used to create circular economies in cities to overcome existing challenges such as resource depletion, climate change adaptation and degradation of ecosystems [2]. It is widely recognised, that NBS have potential to assist the transition from current conventional education paradigms towards to a more critical systemic thinking in order to foster environmental, social-economic, political, economic, and cultural changes, and to address transversally urban challenges such as air quality, sustainable water management, participatory planning and governance [3]).

Despite it is clear and accepted by expert community that NBS can enhance circularity in cities, the pathway to their implementation is still long and facing different barriers [2]. One of them is appropriate awareness rising and education on NBS which should be provided thoughtfully, inclusively and in well organised manner. As NBS implementation requires extremely interdisciplinary approach, the latter should be used also in education on NBS. Current lack of interdisciplinarity in majority of formal education systems limits the communications between different experts. There is a need to educate new generation of experts, and enhance the ability of professionals to be able to communicate with different expert and lay communities. Formation of interdisciplinary educational groups combining various types of knowledge or sciences like for example social, environmental and biology sciences, enables formation of new types of interdisciplinary pedagogies which combine students and pedagogues from various areas in an effort to create new, future experts capable of responding to complex challenges posed by climate change and lack of implementation of sustainable development in practice (on terrain).

In this chapter, (1) we briefly review available environmental education materials related to NBS, (2) we present selected case studies that describe educational activities for three main stakeholder groups, i.e., pupils and students, professionals such as practitioners and city administrators, and the general public (Fig. 19.1), and (3) we summarise information on existing online platforms for knowledge sharing in the field.

Environmental Education Materials Related to NBS

Institutional and non-institutional education is a crucial element in creating a positive impact on environmental behaviour. The successful implementation of the European Green Deal must also be carried out through educational system reforms to ensure

Fig. 19.1 Examples of activities related to environmental education through applications of NBS concept. **a** Productive Garden and Eco-island @ FEZ-Berlin, Germany; **b** School garden, 'Colegio Sagrada Familia', Spain; **c** NBS for informal environmental education, Greater Porto, Portugal *(Source* LIPOR, 2021); **d** Green–Blue: Sustainable Urban Drainage Project, Spain (*Source* GCMP Paisajes Resilientes https://paisajesresilientes.wordpress.com/2019/05/25/verde-azul_proyecto-de-drenaje-urbano-sostenible-dus-en-ceip-luis-bunuel-green-bluish_suds-project-in-school-luis-bunuel/); **e** NBS for building system recovery, Italy (*Source* Sapienza Master in Architecture students, 2021); **f** Green Roofs Literacy, Portugal; **g** Demo green wall for greywater treatment, Slovenia; **h** Demo green wall for improving indoor air quality, ETSIA-US, Spain; **i** LE:NOTRE Landscape Forum, EU (*Source* LE:NOTRE Student Competition 2021); **j** Courses of ANCV-Portuguese National Association of Green Roofs, Portugal; **k** Urban greening course, COIAA, Spain; **l** Demo centre of green technologies, Slovenia (*Source* Arhem Ltd. 2020); **m** MUGLI – a Mobile Exhibition Space, Austria (Source: https://gruenstattgrau.at/mugli/); **n** Animation Video, COST Action Circular City; **o** Sant Narcis 'Edible Neighbourhood', Spain

that all are equipped to meet the challenges of the future, including in those related to labour market. Therefore, 'tailored educational curricula' [4] must contain key competencies and skills needed to support a green economy. Socially and environmentally responsible behaviours may be further reinforced by impermanent education (such as through workplace retraining). Education for the future is a social challenge attached to the importance of public organizations dealing with the environment and climate change. Table 19.1 summarizes EU and international organizations dedicated to promoting environmental educational activities.

Table 19.1 European Union and international organizations dedicated to promoting environmental education activities

Organization	Description	Educational activities	Link
The United Nations Economic and Social Council (ECOSOC)	The ECOSOC supports non-profit public, volunteer organizations through consultation and access to United Nations economic and social council	Helps addressing social and economic SD challenges and improving human rights (where environmental protectionism a human right) as well as to support 'ad hoc' decision processes	https://www.un.org/ecosoc/en
The Academic Council on the UN System Institutional Member (ACUNS)	ACUNS is a global professional association of educational and research institutions, individual scholars and practitioners active in the work and study of multilateral relations, global governance and international cooperation	Promotes teaching on environmental topics, as well as dialogue and mutual understanding across and between academics, practitioners, civil society and students. Helps publishing position and opinion papers	https://acuns.org/
The European Environmental Bureau (EEB)	The EEB is Europe's largest network of environmental citizen organisations. The EEB brings together around 140 civil society organisations from more than 30 European countries. The EEB supports sustainable development, environmental justice and participatory democracy	Carries out a wide range of activities in environmental prevention and protection, among which include supporting young people in their concerns about climate change (https://eeb.org/library/pan-european-survey-climate-to-priority-for-youth/) as well as supporting NGOs and their initiatives in sustainable consumption (https://eeb.org/library/eu-strategy-for-sustainable-textiles-ngo-position/)	https://eeb.org/

(continued)

Table 19.1 (continued)

Organization	Description	Educational activities	Link
Environmental Ambassadors Sustainable Development (EASD)	EASD is one of the newest EEB members. They are a non-profit professional association working in science and research. They work through consultancy, expertise, innovation, education, the promotion of cultural values and knowledge-based advocacy	Popularizing and promoting scientific work, to enhance communication between stakeholders (representatives of local self-government, educational institutions, associations, entrepreneurs, individuals), as well as increasing public interest in sustainable development, environmental protection and education	https://eeb.org/easd-environmental-ambassadors-for-sustainable-development/
The European Citizen Science Association (ECSA)	The ECSA is a non-profit association set up to encourage the growth of the Citizen Science movement in Europe in order to enhance the participation of the general public in the scientific processes	Initiating and supporting citizen-science research and projects, as well as understanding and using its benefits in decision making	https://ecsa.citizen-science.net/
Women Engage for a Common Future (WECF)	A non-profit network dedicated to a gender justice and a healthy planet for all,WECF covers approximately 50 countries, working with 150 partner (women's and civil society) organisations in networks	The promotion of: i) holistic environmental solutions (reflecting individuals' lives); ii) gender equality and women's human rights as interconnected to climate justice; iii) sustainable energy and chemicals, reduction of toxic waste, safe water and sanitation for all	https://www.wecf.org/

(continued)

Table 19.1 (continued)

Organization	Description	Educational activities	Link
Innovation Hive	Innovation Hive is a private non-profit organization located in Greece, specialized in research and innovation	Developing educational materials, training activities and practice-driven courses that focus chiefly on systemic problems and are tailored to educators, schools across educational levels, youth and adults	https://innovationhive.eu/about-us-inno/
The Foundation for Environmental Education	Engaging and empowering individuals through education in collaboration with its members and partners worldwide	Empowering students to be leaders for sustainability and positive change through enhancing global education programs (Blue flag, Green key, Young Reporters, Learning about the Forest and Eco-schools)	https://www.fee.global/
The International Association of Universities 'Horizons'(IAU)	The IAU is the leading global association of higher education institutions and university associations. It has over 600 Member Institutions and 30 organizations	Transforming higher education for the future. It publishes a twice annual magazine outlining IAU activities	https://www.ecoschools.global/resource-material
Eco-schools	Eco-Schools has developed from a European educational programme to a global model for environmental education and sustainability	Promoting the education of students participating in the programme (workshops, eco-schools) whose actions help developing values, attitudes and behaviour towards the environment	https://www.ecoschools.global/our-history

(continued)

Table 19.1 (continued)

Organization	Description	Educational activities	Link
LE:NOTRE Institute	The LE:NOTRE Institute has been established under the auspices of ECLAS, the European Council of Landscape Architecture Schools, as an umbrella organisation for interdisciplinary collaboration between education, research and innovative practice in the landscape field. The goal of the LE:NOTRE Institute is to develop and strengthen the links between landscape education, research and innovative practice, in the public, private and not for profit sectors	What makes the LE:NOTRE Landscape Forum different from other European landscape events is the focus on dialogue, debate and discourse. It provides a unique opportunity to interact creatively with colleagues from a range of landscape disciplines in informal workshop and field visit settings. The aim is to create stimulating environment to promote the generation of both new teaching ideas and projects, for research and for collaboration between theory and practice	https://forum.ln-institute.org/lenotre-institute-2/

There is a widespread scientific opinion that mitigating pollution overall may be better carried out through increased public knowledge of environmental issues. The end result is to reinforce behaviours that promote environmental prevention and protection. Social movements in general and the environmental movement in particular are based on the premise that public education helps giving rise to supporting environmental protection and reducing the effects of climate change. Among many other definitions, the European Commission recognizes NBS as those supported by nature and ecosystems [5]. As opposed to advanced technological solutions, NBS are cost-effective, simultaneously provide environmental, social and economic benefits, as well as help building resilience to climate change. NBS public acceptance coupled by environmental education (awareness supported by knowledge) is a key for future NBS implementation. Table 19.2 provides a partial list of EU and international NBS projects along with their educational activities and initiatives.

Examples for Environmental Education Activities for Main Stakeholder Groups

Pupils and Students

FEZ-Berlin, Germany

The FEZ-Berlin is the largest Children, Youth and Family Centre in Berlin, Germany (https://fez-berlin.de/en/). It featured an eco-island (Fig. 19.1a) with a small 'tomato-fish' aquaponic system coupling fish and tomato production. The children learn about this form of sustainable food production, in which the fish water does not have to be disposed of as wastewater, but is used to irrigate and fertilise the plants. They take measurements, such as the pH value of the water, and harvest tomatoes themselves. Ms. Baganz from the research project CITYFOOD (https://www.cityfood-aquaponics.com/), which accompanies this NBS, points out that the idea of sustainable food production through aquaponics, which takes place in cities, resonates well with the children and fits with the eco-island themes of global thinking and healthy eating.

The eco-island comprises further NBS units: composting, soil improvement and conservation, urban meadows, productive garden, urban forest, and biochar/hydrochar production. In a narrative interview conducted in June 2021, Ms. Kulla from the FEZ's 'Education for Sustainable Development' team explained how they enhance environmental education: '*These are often city children who do not have much direct contact with nature. Here, the children experience nature, respect it and feel comfortable in it, they observe, learn and try out experimental ways of working. They experience biodiversity and recognise connections, even circularities. And deal with the question of how we want to live in the future. But the most important thing is that the children learn with all their senses, that they turn this into knowledge and finally integrate it into their actions*'.

Table 19.2 NBS projects and their promotional activities (education materials and initiatives)

Project title and web site	Funding (Duration of Funding)	Project's goal	Promotional activities (education materials/initiatives)	Target group	Link
Implementing nature based solutions for creating a resourceful circular city www.circular-city.eu	Horizon 2020 program, Cost Action CA17133 (2018–2021)	To create greener urban environments, enhance resource recovery and implement holistic social-economic solutions for the development of circular cities	#Mycircularcity photo contest (To promote functional and aesthetic values of NBSs in urban circularity)	Laypersons, researchers & professionals	https://circular-city.eu/?p=680
Making Cities Resilient 2030: My City is Getting Ready https://www.unisdr.org/campaign/resilientcities/advocates	UN Office for Disaster Risk Reduction (UNDRR) (2020–2030)	To establish a unique cross-stakeholder initiative that improves local (city) resilience through advocacy, sharing knowledge and experiences	Mayors and children leading the fight against climate change in the Philippines	Children	https://www.unisdr.org/campaign/resilientcities/news-events/article/17160/mayors-and-children-lead-fight-against-climate-change-in-the-philippines
New and emerging challenges and opportunities in wastewater treatment http://www.nereus-cost.eu/	Horizon 2020 program, Cost Action ES1403 (2014–2018)		A children's book: 'The Secret Handbook of the Blue circle'	Children	https://www.iwapublishing.com/news/secret-handbook-blue-circle-qa-blog-dr-despo-fatta-kassinos

(continued)

Table 19.2 (continued)

Project title and web site	Funding (Duration of Funding)	Project's goal	Promotional activities (education materials/initiatives)	Target group	Link
Nature-based Solutions Pilot teachers - Exploring Nature-Based Solutions in Your Classroom https://www.europeanschoolnetacademy.eu/courses/course-v1:Scientix+NBS+2021/about#behind	European School net Academy, European Commission (www.eun.org (January – September 2020)	15 teachers have joined the NBS project to help developing learning scenarios to integrate NBSs into the classroom	Online course on NBS (15 scenarios)	While open to all, the main target groups are primary and secondary school teachers from Europe and other regions	https://www.europeanschoolnetacademy.eu/courses/course-v1:Scientix+NBS+2021/about#topics
Grow Green http://growgreenproject.eu/	Horizon 2020 (2017–2022)	To create climate and water resilient, healthy and livable cities by investing in NBS	The Citizen engagement for NBS: Fact Sheet	The general public	http://growgreenproject.eu/wp-content/uploads/2021/03/GrowGreen-factsheet-2021-v02-1-2.pdf
UNaLab https://unalab.eu/en	Horizon 2020 (2017–2022)	To develop smarter, more inclusive, more resilient and increasingly sustainable cities through the implementation of NBS	'Urban Lab Playground: the Co-creation Game' An interactive game through which players will co-create a story line to fight against a climate-related challenges affecting our cities today	The general public, but targeting urban dwellers	https://unalab.eu/en/events/urban-living-lab-playground-co-creation-game

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Table 19.2 (continued)

Project title and web site	Funding (Duration of Funding)	Project's goal	Promotional activities (education materials/initiatives)	Target group	Link
Urban Green Up	Horizon 2020 (2017–2022)	To develop, apply and replicate 'Renaturing' Urban Plans with the aim to mitigate the effects of climate change, improve air quality and water management, as well as to increase the sustainability of cities through innovative NBS	Participation contest in Valladolid—Re—naturalise your city	Neighbourhood communities, educational centres, cultural associations	https://www.urbangreenup.eu/news--events/events/re-naturalise-your-city.kl
ProGIreg https://progireg.eu/	Horizon 2020 (2018–2023)	ProGIreg uses nature for urban regeneration with and for citizens	'proGIreg therapeutic garden' for disabled users, with green spaces for activities, relaxation and learning. It has also a 'mini-farm' for urban gardening	Disabler citizens	https://progireg.eu/news/?c=search&uid=OqiEzKpr
UrbiNat https://urbinat.eu/	Horizon 2020 (2018–2023)	URBiNAT aims to regenerate and integrate underserved city districts. The interventions focus on public spaces and the co-creation, together with citizens, of new social and NBS within and between neighbourhoods	'Focus Groups in situ' combines walking around an intervention area, observation and interviews, allowing the evaluation of positive and negative aspects to develop with the citizens an integrated vision	Citizens (including children)	https://urbinat.eu/nbs_catalogue/focus-groups-in-situ-2/

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Table 19.2 (continued)

Project title and web site	Funding (Duration of Funding)	Project's goal	Promotional activities (education materials/initiatives)	Target group	Link
Naturvation https://naturvation.eu/	Horizon 2020 (2016–2020)	The goal was to understand what NBS could achieve in cities, how innovation could be fostered, and contribute to realising the potential of NBS for responding to urban sustainability challenges	The 'Oasis for Children' aims to implement non-institutional education in 5 primary schools in Zagreb. It aims to educate pupils outdoors in school gardens, on environmental protection, sustainable development, healthy lifestyles and volunteerism	Children	https://naturvation.eu/nbs/zagreb/oasis-children
Nature4Cities https://www.nature4cities.eu/	Horizon 2020 (2016–2020)	Nature4Cities aimed to creating a comprehensive reference Platform for NBS, offering technical solutions, methods and tools to empower urban planning decision making	'Bird-Friendly garden' is one of Nature4Cities pilot sites, a school garden with diverse vegetation allowing to magnetize fauna. With a community and an educational strengthen aspect in the quality of life and in the environment, which became more peaceful, with decreased noise and air pollution	Children	https://www.nature4cities.eu/post/pilot-site-bird-friendly-garden-szeged

'Programa Aldea' (Aldea Program)—Environmental Education for the Educational Community in the Province of Andalusia, Spain

The Aldea Program: Environmental Education for the Educational Community was implemented by the Ministry of Education and Sports, and the Ministry of Agriculture, Livestock, Fisheries and Sustainable Development, in the Andalusian educational system (Southern Spain) since 1990. Updating the environmental educational offer and initiatives from a holistic perspective, the Aldea Program aims to promote innovative didactic approaches for the conservation of natural resources and the promotion of sustainable development within the Andalusian educational community.

With the intention of contributing to a more pro-environmental, just and supportive society, the Program is based on the four educational pillars proposed by UNESCO (United Nations Educational, Scientific and Cultural Organization): learning to know; learning to do; learning to live together; and, learning to be [6]. Thus, the Aldea method promotes: the development of students' key competences; the exchange of educational experiences; the work in group; the creation of professional networks; the work by projects; and other active and advanced methodologies that ultimately stimulate a change in the environmental behaviours with nature, affecting daily educational practice.

A deliverable of the Aldea Program is a Catalogue of Environmental Education Program which included the entire environmental education programs and projects—e.g., the Eco-School program [7, 8]—promoted by the Regional Government of Andalusia. The school 'Colegio Sagrada Familia, Las Francesas' (Córdoba, Andalusia) is one of the participant institutions, being involved in the program with environmental education activities on climate change, recycling and biodiversity, as the case implementation in 2021 of a school garden in its facilities (Fig. 19.1b).

NBS for Informal Environmental Education, Greater Porto, Portugal

Natural environments like green spaces have a meaningful impact on citizens' health and wellbeing [9], being inclusive NBS governance important to redresses inequalities [10]. The educational potential of NBS can be largely explored in informal education programmes for children and their families. LIPOR (Intermunicipal Waste Management Service of Greater Porto), a Municipality Association that manages, recovers, and treats the municipal waste produced in 8 municipalities of Greater Porto Area (https://www.lipor.pt) is a community-oriented company that embraces innovative projects and services, inspired by the principles of circular economy (CE). Geração + (Generation +) project was initiated in 2014 by LIPOR, motivated by the need to implement an integrated Environmental Education and Intervention strategy in the community.

The target audience of this educational project includes public/private schools (92% of 295 registered institutions, Fig. 19.1c), as well as social institutions, other associations and entities that intend to change environmental management practices.

Based on its intervention in optimizing the institution's environmental processes, Geração + works to develop practices that promote balanced waste management meeting the waste management hierarchy, by addressing several themes: reducing, re-using, recycling waste, composting, organic farming, food waste, biodiversity, water, energy, sustainable consumption, management of green spaces, and good practices of natural resources management. In each intervention area, concrete actions are carried out on the ground, thus allowing concrete economic gains for the institutions. The gains for LIPOR include the increase in recyclable waste sent for recovery and the reduction of the undifferentiated fraction of waste sent for energy recovery.

Green - Blue: Sustainable Urban Drainage Project, Spain

The project 'Green–Blue: Sustainable Urban Drainage Project' was proposed by students from the Agrarian Department of the Institute of Secondary Education No.1 (Universidad Laboral de Málaga) in the Call 'Learning with companies 2018', to the Luis Buñuel Center for Early and Primary Education (Málaga, Spain. The project, granted with 6,000 EUR, pursued the dynamization of the relations between educational centres and productive sectors.

The project is based on three pillars: (1) Sustainable Urban Drainage (SUDS); (2) participation and (3) Learning by Service—ApS. In this sense, the community service is materialized in the CEIP, where a double need was detected: (a) technical, due to the drainage problems in free areas on rainy days, difficulting transit and space use, and (b) environmental, to create a qualified space from the environmental point of view (e.g., CO_2 sink, climatic comfort, health); while working on the perception and potential of the playground as a learning space.

In the project, infiltration trench and rain garden were implemented by the CCFF students in a surface area 870 m^2, to solve a flood problem. Despite the small scope of the intervention, its design and execution has made possible to visualize the potential of Green Urban Design (GUD) in the field of integral management of water at an urban scale.

A multidisciplinary team was involved in the project development (DJP, E. Mediterraneum SL, Cuarto Creciente, Malaga City Council, the architect Celia Martínez, among others), which shows the integrative vision that the planning and management of green areas requires (Fig. 19.1d). The project was structured in three phases: Phase 1. Participation and analysis of the current situation; Phase 2. Design and construction; and Phase 3. Maintenance and community celebration.

The project started the 4th June 2018 with the workshop 'Transforming the playground through nature', focused on addressing the school playground transformation through natural elements; educating about its needs and uses; and the participatory methodologies necessary for this transformation, involving the entire educational community.

NBS for Building System Recovery, Italy

In the environmental technological design studio taught at the Faculty of Architecture of 'Sapienza' University of Rome, students are asked to develop their project focusing on NBS specialized design strategies and construction techniques to implement adaptive interventions aiming at circular cities, resilient architecture, and inclusive urban settings (Figs. 19.1e and 19.2).

The key learning objectives are: the provision of cultural and methodological references and technical and operative tools to realize NBS interventions at multiple scales [11]. The goal is to sensitise students to the need of long-run equilibrium conditions among settlements, anthropogenic activities, and natural capital, in a dynamic scenario of technological innovation and circular metabolism.

From the urban circularity challenges (UCCs) identified by Langergraber et al. [11] and Atanasova et al. [12], 'Sapienza' students concentrate on how best NBS can solve issues related to the Building System Recovery challenge [12], experimenting green walls (GW), green roofs (GR), rain gardens (biorentention cell), bioswales, treatment wetlands; and measuring integrated benefits at multiple scales, especially with respect to water cycle, water-energy nexus, and sustainable heritage restoration.

Urban NBS for circular cities is an evolving concept, where the urban ecosystem—a place of interaction between biotic and abiotic elements—represents the complex and vital system by which to pursue the rebalancing imposed by the erosion of resilience abilities due to climate change. In particular, the building's envelope and the open spaces that counteract fragmentation due to increasingly intense flows of people, materials, and information, as well as other surfaces and infrastructures.

Green Roofs Literacy, Portugal

GR are NBS that deliver a wide range of ecosystem services and perform important roles related to Water-Energy-Materials-Food-Ecosystem nexus in cities [13–15]. It is thus crucial to address the importance of GR at the level of ungraduated students, relating pivotal subjects for comprehension of the Earth System, human settlements and support the build-up of the adaptive and mitigation capacity of cities towards resources circularity [16, 17].

Three proposals are presented for educational activities addressing GR to be used by teachers or course instructors:

- GR conceptual modelling exercise: intents to support the understanding of GR as urban ecosystems through a conceptual model, enabling to communicate in a graphic language, acting as a facilitator tool to interact across different disciplines [16, 17].
- City model exercise: intents to build a maquette of a city and incorporate NBS (e.g. GR), that are of relevance to provide the students with a view of an interconnected and resourceful city, towards achieving an urban CE (Fig. 19.1f).

Fig. 19.2 Examples of design outcomes related to environmental education through application of NBS concept (students: E. Amoroso, D. Antonelli, R. Belmonte, A. Caterino, 2021)

- GR field trip: intents to deliver a clear view of how GR integrates the building and the landscape, as its interaction at different levels (social, environmental and economic).

In order to face the actual challenges for climate change adaption and mitigation and to build up more resilient societies, it is important that subjects such GR, are included in the educational programmes of the schools and at higher education level. Furthermore, there is an increasing need to have tools and educational resources available for teachers to be able to underpin hands-on examples in order to cover different fields of knowledge and entail an interdisciplinary approach.

Demo Green Wall for Greywater Treatment, Slovenia

GW can be applied to treat greywater for reuse while having simultaneous multifunctional services such as improving buildings' aesthetics, outdoor or indoor air quality, carbon dioxide (CO_2) trapping and oxygen production, temperature and acoustic comfort. Therefore, greywater separation and reuse is not only providing an alternative water source but is also a measure that can have numerous additional benefits. At the Faculty for Civil and Geodetic Engineering at the University of Ljubljana, a pilot GW (Fig. 19.1g) is serving not only for research and education purposes but also contributes to the outlook of the entrance hall and is used for promotional activities of the Faculty.

The GW was set up in 2019 and is treating synthetic greywater in horizontal flow through permeable substrate filled in four rectangular cascading beds. Additionally, a heat exchanger was set up in collaboration with the Faculty of Mechanical Engineering to study heat transfer from greywater to sanitary water. The wall is planted with indoor plants than can tolerate permanent flooding.

The GW has been used for master thesis [18] and practical work of engaged students in subjects where the concept of closing the water cycles is lectured. The subjects Wastewater treatment and Environmental technologies are available for more than a decade; however, the specific content on closing the loops is lectured since the last 3–5 years. Despite the appealing study programme and the relevance of the topic, the number of students is relatively low. The Faculty thus carries out active promotion through different media, including video and live presentations, where especial focus is given to hand on training and pilot plants such as the GW.

Pilot for Phytoremediation of Air and Water through Vertical Greening Systems in the School of Agricultural Engineering at the University of Seville, Spain

NBS demonstration sites at the School of Agricultural Engineering (ETSIA) of the University of Seville (US), Spain, consist of the application of vertical greening systems (VGS)—i.e., wall-based green facades [11]–, to improve air quality inside buildings and water quality in ornamental ponds in the form of biofilters, and the reuse of wastewater (grey stream) and rainwater [12].

Two demonstration wall-based green facades were installed in- (Fig. 19.1h) and out-side the main entrance of the ETSIA's building, being composed of about twenty different plant species (e.g. *Ajuga reptans 'Atropurpurea'*, *Begonia rex*, *Carex flacca 'Blue Zinger'*, *Carex oshimensis 'Evergold'*, *Chlorophytum comosum*) to maximize the removal of elemental pollutants in terms of phytoremediation. The outside vertical greening—with 6 m^2 of landscape area—is integrated within an aquaponic system—i.e., pond of 20.4 m^2 and about 5,500 L of capacity with ornamental fish and aquatic plants–, which contributes to provide an additional benefit on the water purification processes, and offers recreation opportunities available at the urban University environment [19].

The potential of effective NBS to improve the environmental quality, via alleviating indoor air contamination condition, is of high interest for social innovation, both on a public and scientific level [20]. In this sense, University's students in NBS monitoring, learn and become aware about the urban pollution effects—which are directly involved with the health and well-being of the citizens–, fulfilling one of the fundamental objectives of the Academia, such as being at the service of society.

The LE:NOTRE Landscape Forum, Europe

The LE:NOTRE Landscape Forum is a discourse-oriented and interdisciplinary event of four days duration. The Forum focuses on local landscapes and the sustainability challenges they are facing. In accordance with the European Landscape Convention this includes outstanding as well as every day or degraded landscapes in urban, peri-urban, and rural environments.

The LE:NOTRE Landscape Forum is a place for interdisciplinary and multistakeholder exchange on NBS, where European students and faculties meet with city administrators, planners, architects, landscape architects, NGOs (non-governmental organisations) as well as other stakeholders. The first Landscape Forum was held in Antalya, Turkey, in 2011. The event has continued on a yearly basis since then, moving across various European locations. In 2015, the Student Competition was introduced to make the Landscape Forum more inclusive and relevant for the international community. Since then, the outcomes of the Student Competition have greatly enhanced the quality and innovation potential of the Forum as a whole.

The 2021 International Student Competition, as part of the 10th Landscape Forum of the LE:NOTRE Institute, was launched in October 2020, and was organised by the Faculty of Architecture and Design at the Academy of Fine Arts in Gdańsk, in cooperation with Gdańsk Urban Development Association. The results of the Student Competition were announced through a virtual kick-off event in April this year 2021 (https://forum.ln-institute.org/lenotre-international-student-competition-2021/), with the active participation of the students, faculties, the City of Gdańsk administrators, practitioners and various stakeholders, as well as IFLA Europe (European Association of Landscape Architects) (Figs. 19.1i and 19.3).

Fig. 19.3 Examples of winning entry in LE:NOTRE Landscape Forum student competition, related to environmental education through application of NBS concept (International Master in Landscape Architecture students from Weihenstephan-Triesdorf University of Applied Sciences and Nürtingen-Geislingen University, Germany)

Professionals

Courses of ANCV-Portuguese National Association of Green Roofs, Portugal

The NGOs or associative movements that are engaged with green infrastructure (GI) and NBS can act at different levels towards its promotion and dissemination. They often play the role to set collaboration between stakeholders and other interested parties. Besides that, they are crucial to enhance circularity in cities with NBS, providing awareness and technical knowledge through courses and short hands-on approach events [21]. As an example, is presented the case study of the Portuguese National Association of GR (ANCV, Associação Nacional de Coberturas Verdes) (https://www.greenroofs.pt). This NGO, intents to promote NBS in cities, especially GR and GW leveraging their importance and contributions to promote the creation of healthy, sustainable, biodiverse and resilient urban territories. Technical and advanced courses have been delivered in collaboration with professional orders (Ordem dos Arquitetos and Ordem do Engenheiros da região Norte), and intermunicipal communities as representative of several counties. Collaboration is also been set with schools, at the basic and secondary level, and also at the higher education level (e.g., Universities, Polytechnics), to deliver short courses or talks on the subject (Fig. 19.1j).

A strategy of dissemination and environmental education is needed to show the population, and the different groups of professionals related to the theme, the diverse and significant benefits that they offer. A key point is the literacy concerning the GR that should be escalated from the pre-school to higher educational levels, whereas technical knowledge should be assured for widespread of the technology. The role of the GR associations is very important to set a voice connecting companies, policymakers, academics, schools and citizens.

The Official College of Agricultural Engineers of Andalusia, Spain

The Official College of Agricultural Engineers of Andalusia (Colegio Oficial de Ingenieros Agrónomos de Andalucía, COIAA)—founded in 1953 –, is a Public Law Corporation which represents the Agricultural Engineering in Andalusia (Southern Spain), providing social guarantee and services for the profession. Training courses is one of the COIAA services aimed at updating or improving certified competences, knowledge and skills—appropriate to current technologies and regulations—among its professionals and practitioners (see Fig. 19.1k for details). The planning and management of training actions is entrusted to the Andalusian Foundation of Agricultural Engineers (Fundación Andaluza de Ingenieros Agrónomos). Several categories are distinguished in its wide training offer, among them: food quality and safety, and environment and renewable energies; being in the latter where the course on VGS and GR is categorized. Those interested in the urban greening course belong to the areas of knowledge in the field of NBS (landscaping and GI); and intended to develop their career as engineers, environmental consultants and technicians. The training course program and learning activities, with the following main educational contents, are classified as:

- Urban greening: urban sustainability and benefits of urban GI.
- Built urban environment: green buildings (VGS and GR).
- Project design and implementation: technical aspects and planning.
- Irrigation and drainage systems: use of rainwater and greywater.
- Maintenance: plant protection, lighting, advanced control systems and equipment.
- Technical visits (i.e., VGS and GR implemented in the city of Seville).

Demonstration Centre on Green Technologies in Ajdovščina, Slovenia

The demonstration centre of green technologies (Fig. 19.1l) is located at the premises of the central wastewater treatment plant (WWTP) in the small town of Ajdovščina. In the framework of national research projects by the University of Ljubljana various pilot systems of NBS have been set up at first only for research purposes. Two stage constructed wetland (VF-HF), high-rate algae pond, evapotranspirative willow system and lysimeter field are demonstrating robust and sustainable treatment of municipal wastewater, production of safe and valuable side products (woody and algae biomass) and reuse of reclaimed water for vegetable fertigation in lysimeter field. The initial goal of the site that covers 1000 m^2 was to research, develop, optimize, and demonstrate NBS technologies, their products and impact on agriculture [22, 23].

After initial research activities to overcome technological barriers, the site was promoted for educational activities. First, field excursions and master thesis for students of different pre- and post-graduation environmental studies were carried out, followed by international summers schools. Later, the operator of the WWTP recognised the value of the centre to demonstrate the possibilities of NBS for decentralized wastewater treatment in small rural communities. Visits of decision makers and end users from different municipalities have been organised to present treatment wetland and banish doubts on its performance. Recently, the centre was presented to farmers which increased interest in use of reclaimed water.

Currently the centre is still closed for public, so only pre-announced visits are possible with an expert guide from the University of Ljubljana or water utility company. The plan is to turn the site from research focused centre into an open demonstration and educational centre where different target groups can learn about sustainable approaches in wastewater management and principles of closing the nutrient and water cycles. The centre will be refurbished into an attractive site for visitors with suitable infrastructure for outdoor learning courses (information boards, banks, outdoor classroom). The site would also be freely accessible and connected to local cycling route across the valley as one of the spots of interest.

General Public

MUGLI – a Mobile Exhibition Space, Austria

MUGLI (Fig. 19.1m)—the acronym stands for Mobile Urban Green Living Innovative—is the mobile exhibition space of Grünstattgrau, which is the Austrian competence centre and central coordination unit for the future of urban green environment, and innovations and ideas for green cities. The network comprises about 380 partners from the field. Since 2018, MUGLI tours through Austria (e.g., Vienna, Linz, Feldkirch, Klagenfurt) specifically for activities related to knowledge, participation management and economic and social cooperation regarding GI and NBS on buildings. MUGLI allows a first-hand experience of greening buildings and provides information and knowledge to a broad range of people. It is also a modular experimental space for existing and new technologies of the network partners. MUGLI shows different systems for the greening of roofs and both external and internal VGS. Visitors are informed by means of a guided exhibition. Through this interactive tour you will find out which different vegetation systems are possible, how different technologies work and which technology is behind them. In addition, monitoring data on the areas are used to generate measurement data for the individual systems. Through the periscope you can explore the GR with the wild bee hotel and the photovoltaic system. How nature can be combined with architecture shows MUGLI with the exhibition of beneficial devices such as nesting aids for swifts and wild bees. MUGLI aims to raise awareness and highlight the role of GI in cities to improve the quality of urban living [24].

Animation Video, COST Action Circular City

To promote its ideas, the COST Action Circular City (https://circular-city.eu/) developed an animation video (Fig. 19.1n) with English speaker voice. With the video, a positive scenario of the future using NBS in cities is shown. It is explained, how cities by using NBS can become green, beautiful, CO_2 neutral and resilient.

In the video, solutions on all levels are shown:

- Green building materials, including bio composites with plant-based aggregates;
- Green building systems, employed for the greening of buildings by incorporating vegetation in their envelope; and
- Green building sites, emphasizing the value of vegetated open spaces and water-sensitive urban design.

On the building level, the video showcases the use of plants and NBS building materials, the important role of NBS in water purification and retention as well as how buildings can be transformed as producing cell of the city. In public spaces such as parks and roads, NBS are utilised for storm water management and for prevention of urban heat islands.

The video is available at the COST Action's YouTube® channel (https://www.youtube.com/channel/UCofffnNso64Ck1limndfvTw). Besides the English speaker, the function to implement subtitles has been used to guarantee that general public can more easily understand the message of the video. Thus, the English subtitles have been translated by members of the COST Action Circular City into 34 languages. These include all national languages of the 39 COST countries, some regional languages in the COST countries (e.g., Catalan (Spain)) as well as other languages (e.g., Arabic, Chinese).

The Social Project 'Edible Sant Narcis Neighbourhood', Spain

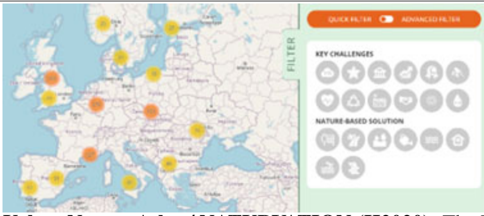
The social project 'Edible Sant Narcis Neighbourhood' started at the end of 2019. The project seeks to co-create and implement NBS, such as a community gardens, rainwater harvesting and GW, for closing the water and nutrients cycles and enhancing social engagement and awareness regarding a green and just transition (Fig. 19.1o). Inside the community garden itself, an innovative design concept for GW will be built, which puts together CE principles and NBS for treatment and reuse of greywater for urban agriculture at urban scale: the 'WETWALL' [25]. The co-creation process employs a participatory planning methodology, including from the onset municipality representatives and local stakeholders. The long-term expectations are to transform this neighbourhood into an example to be followed in terms of participative creation and implementation of circular NBS. Moreover, in a near future, the project is expected to include experimental sessions with secondary, graduate and postgraduate students of the University of Girona in order to transfer technical knowledge on design and implementations of GW and community gardens, raise awareness concerning its relevance for climate change mitigation and collect feedback regarding constraints and enablers for the uptake of such NBS.

Online Platforms for Knowledge Sharing

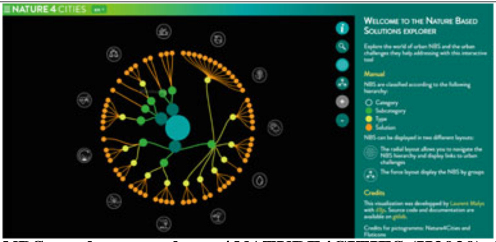
The current demand of civic society, public, private and research organisations for more sustainable and resilient cities along with limited knowledge sharing on NBS technical and practical advancements has led to the rise of online platforms to facilitate the knowledge exchange for a proper mainstreaming of NBS in cities. Therefore, in the past 5 years, a great variety of online platforms including diverse format do knowledge sharing such as catalogues, databases, interactive forums, and networking spaces and have been developed under the scope of European research and innovation programmes to support knowledge exchange on operation and maintenance of NBS. Some examples of available *online platforms for knowledge sharing* can be seen in Table 19.3.

The online platforms presented in Table 19.3 are only a small piece of what has been done in terms of online tools for knowledge sharing on NBS. Out of 70 NBS

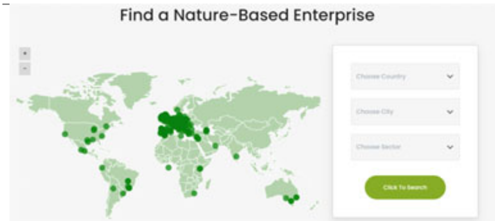
Table 19.3 Examples of online Platforms for Knowledge Sharing



Urban Nature Atlas / NATURVATION (H2020): The Urban Nature Atlas is a collection of more than 1000 inspiring NBS from European cities and beyond. It offers the option of browsing NBS per location, type of NBS (e.g., external building green, allotments and community gardens), focus (e.g., creation of new green areas, protection for natural ecosystems), initiating organization (NGOs, private foundation) and key-challenges addressed (based on Eklipse framework [3] and Sustainable Development Goals (SDGs); e.g. cultural heritage, water management)



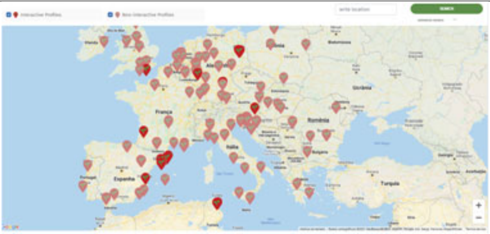
NBS catalogue explorer / NATURE4CITIES (H2020): The NBS catalogue explorer showcase more than 50 typologies of NBS classified as strategies (urban planning, protection and conservation), actions (monitoring, waste management, urban green spaces management) and physical projects (buildings, water, on the ground). The NBS are linked to potential urban challenges to be adressed (adapted from Eklipse framework [3]. Additionally, the tool offers information such as a brief description, potential co-benefits to be delivered, implementation scale and gives the possibility of downloading a comprehensive factsheet

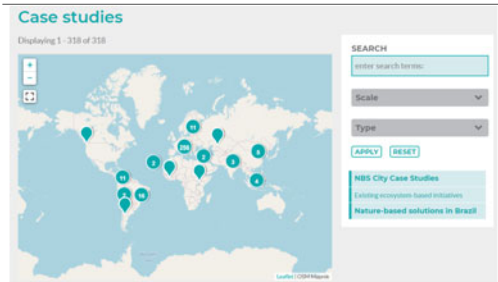


Connecting Nature Enterprise Platform / (H2020): The Connecting Nature Enterprise platform is an online marketplace that aims to connect a wide range of NBS enterprises and organizations (e.g. individuals, enterprises, city councils, private developers, researchers, policy makers) in order to facilitate the knowledge sharing on design, management and monitoring of NBS as well as the diffusion of products/services for the planning, delivery and/or stewardship of NBS, either for economic or non-economic purposes. Therefore, the platform connects suppliers of nature with buyers of nature, nature-based enterprises with financing, innovators with those seeking inspiration, policy-makers with practitioners

(continued)

Table 19.3 (continued)


Interactive catalogue/EdiCitNet (H2020): The interactive catalogue aims to consolidate information about worldwide edible NBS (eNBS) while promoting knowledge sharing, networking, and learning among people involved or willing to get involved with these initiatives. It delivers a comphensive collection of more than 300 eNBS, in which user can get inspiration and interact with. It allows user to explore eNBS per type of products and activities offered, initial budget required, type of advertisement and funding. Aditionally, user can access the profile of eNBS to get more detailed information such as a brief description, products, activities and visual graphs of ECS performance in terms of urban challenges and ecosystem services provided. As an added value, unlike other catalogs, the interactive catalogue facilitates the creation of networks. The tool offers a set of interactive functions that make it a true social network for users. Users can leave comments and questions or follow profiles to receive updates on events and news

Tools for co-creation/UNALAB (H2020): It is a comprehensive catalogue showcasing diverse tools to support procceses for co-creation of NBS. The tools are organized according to the purposes of the co-creation process and offesrs a variety of methods, games, templates, workshops for indentification of suitable NBS in line with end-user needs and goals, generate innovative solutions through unleashing creativity and discovering valuable insights, designing action plans to achieve long-term aims, testing and validation of implemented solutions and evaluate public reaction to a solution

OPPLA: Oppla is an open platform which works as the EU Repository of NBS. It aims to promote the consolidation and creation of knowledge on NBS to better manage the environment. It is designed to support knowledge sharing across a wide range of end-users (e.g. scientistis, policy makers; public, private and voluntary sectors; as well as individuals). Therefore to offer a great variety of services and tools such as *Marketplace and case of studies*, where the latest thinking on natural capital, ecosystem services and NBS is brought together and *Ask Oppla* is crowd-sourced enquiry service designed to support knowledge exchange between users concerning topics related to NBS

tools reviewed under the scope of The ACTionNBS project, approximately 50% were informative and provide guidance through knowledge sharing mechanisms (catalogues, databases, handbooks etc.) [26]. Considering the novelty and worldwide relevance of the NBS topic, such rise number of online platforms and tools are understandable. Hence, nowadays is not a question of developing/enhancing knowledge sharing platform but to promote the integration and communication between such platforms to facilitate public access avoid segregation of end-users and thus favours long-term and suitable knowledge sharing across NBS community. Moreover, existing tools provide limited guidance concerning resources needed and their management in the sense of resources recovery. Therefore, if NBS are to be implemented as a solution to foment a sustainable resources management in cities then the tools require strictly cross-disciplinary approach and thus they must integrate data related to the performance of NBS in terms of water, food, energy, and waste management.

Conclusions

Educational activities through NBS—for which selected examples have been described in this chapter—aim to increase environmental citizenship by identifying specific target groups and reaching out to them (1) the core idea of NBS and (2) the benefits of closed loops using NBS. As different as the target groups are, as different is the approach to them and the teaching content to be imparted.

In formal higher education, existing activities cover ex-cathedra lectures, seminars and excursions, to pilot NBS for students of different graduate and post-graduate programmes. This can be upgraded by the inclusion of invited lectures from practitioners and other disciplines, round tables with businesses and farmers, workshops, hands-on exercises at demo sites, and pilot plants. The aim is to unify, consolidate and upgrade the content regarding closing the water and nutrient cycles, by enriching the existing programmes, or proposing new elective courses. The format of teaching may be improved by:

- Diversifying the existing courses with invited lectures and round tables involving lectures from other faculties and practitioners.
- Including more practical work and hands-on trainings at NBS pilot plants, and elsewhere.
- Proposing a special set of elective courses on this topic at different faculties.
- Enhancing the interdisciplinarity aspects though integration, i.e., combining a set of on-terrain exchange of knowledge, and experiences from a diverse field of sciences that deal with water management (social, environmental, spatial, biology, health, food production etc.).
- Summer schools on closed cycles management.

Additionally, education on NBS and circularity in cities needs to reach out of formal education by developing new curricula and educational activities. Depending on the desired outcome, content and methods must be adapted to target groups with very different requirements, such as children, alumni groups for lifelong learning, members of different chambers (e.g. chambers of Engineers, Agriculture and Forestry, and Architects), farmer associations and urban farmers, vocational trainings at secondary schools, employees at the municipalities, SMEs, and other stakeholders that are identified in a city, as well as the general public. It is important that students of building professions—landscape architects, architects and engineers—exchange experience and co-learn how the integration of NBS into architectural and urban design can help create more sustainable and circular urban settings, for the benefit of people and the environment.

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Chapter 20
Nature-Based Solutions to Promote Environmental Education on Integral Ecological Sanitation

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Abstract The present chapter aims to promote the integral ecological sanitation model, developed under the scope of ECOSAN project (financed by the Environmental Fund of the Ministry of Environment and Climate Action of the Portuguese

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Republic) and to contribute to Environmental Education, in the fields of territory valorization and circular economy. This was accomplished through Environmental Education programs, activities and campaigns aiming at the adoption of more sustainable practices, particularly focused on the efficient use of water and involving agents from several economic sectors, including agriculture, industry and tourism. The development of the integral ecological sanitation model (ECOSAN), based on solutions inspired by Nature, namely "dry or low-flow toilets" and "floating islands/constructed wetlands", pressuposed an open, critical and reflective dialogue on the new environmental challenges, as it intended to promote a new attitude towards the valorization of the water resource, as well as to encourage the creation of more sustainable environmental value, policies and practices, that may induce changes in individual and collective behavior. To this end, education-action activities, conferences/seminars, idea contests, training and capacity building actions that enhance the dissemination of knowledge, environmental awareness campaigns, exhibitions, digital practical guides, educational materials and support resources were developed.

Keywords Environmental education · Dry toilets · Floating islands · Constructed wetlands · Integral ecological sanitation · Sustainable development goal 6 · Water and sanitation · Green infrastructure intelligent irrigation

Introduction

In the Encyclical Letter Laudato Si' ON CARE FOR OUR COMMON HOME, the Holy Father Francis writes that "the urgent challenge of protecting our common home includes the concern to unite the entire human family in the search for sustainable and integral development, because we know that things can change" [1].

This letter briefly reviews different aspects of the current ecological crisis and addresses the issue of scarcity of natural resources, in particular water. Water is a natural resource of paramount importance, indispensable for human life and for sustaining terrestrial and aquatic ecosystems, but in many places, demand exceeds its availability. In many regions of the world, drought is compromising food production

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and the population does not have access to safely managed drinking water. In other places, in addition to the deterioration of water quality, there is a growing tendency to privatize this natural resource, turning it into a commodity subject to the laws of the market [2].

Having in consideration the domestic water use, on one hand, flushing a toilet generally represents a rejection of 3–6 L of drinking water and that, on the other hand, millions of people still die each year from lack of water and sanitation services. Thus, there is still a challenging, but necessary way to go in order to achieve the 6th Sustainable Development Goal defined by the United Nations in its Agenda for 2030, of ensuring the availability and sustainable management of water and sanitation for all [3].

In fact, access to safe drinking water is an essential, fundamental and universal human right, because it determines people's survival and, therefore, is a condition for the exercise of other human rights. The waste of water that occurs, not only in developed countries, but also in developing countries that have large reserves of water, shows that this problem is partly an educational and cultural issue, because there is still no global awareness of the seriousness of these behaviors in a context of great inequality. The analysis of environmental problems implies an analysis of human, family, work, urban contexts, and of each person's relationship with themselves, which generates a specific way of relating to others and the environment. This refers to the issue of integral ecology, which requires that we take the time to reflect on our lifestyle and our ideals. It is essential to seek comprehensive solutions that consider the interactions of natural systems with each other and with social systems. The environmental crisis cannot be dissociated from the social crisis. The challenge that arises is that of a single and complex socio-environmental crisis and the guidelines for the solution require a comprehensive approach to combat poverty, inequality and, at the same time, take care of Nature.

Nature-Based Solutions to Promote Integral Ecological Sanitation

In order to understand how Environmental Education can be enhanced through nature-based solutions, it is important to recall what David Attenborough tells us, in his book "A life on our planet", *Nature is our greatest ally and our greatest inspiration. We just have to do what nature has always done. It is time to establish a life in balance with nature; to start to prosper, to learn to work with Nature and not against it. We got here because we are the most intelligent creatures that ever existed. But to continue, we need more than intelligence; we need wisdom* [4].

The EU Commission defines nature-based solutions as "*Solutions* that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions" [5]. Nature-based solutions must therefore benefit biodiversity and support the delivery of a range of ecosystem services.

The integral ecological sanitation model, developed under the scope of ECOSAN project (financed by the Environmental Fund of the Ministry of Environment and Climate Action of the Portuguese Republic), is based on technological solutions inspired by Nature, of low cost and maintenance, which enable the reuse of the water resource and recycling, mainly of nutrients and organic matter, in a safe way, with the objective of "closing the cycle" and ensuring the circularity between sanitation and agriculture, while contributing to the reduction of drinking water consumption. The ECOSAN model foresees the adoption of dry and/or low-flow toilets with reused water (grey water) and/or rainwater and solid–liquid separation. Urine and other liquid effluents are treated in floating islands with vegetation or constructed wetland systems and biomass is valorised in a composting unit. Treated water can be used for irrigation and the compost can be used as a soil conditioner and/or fertiliser [6]. This model may have a high potential and interest for implementation in rural tourism units, ecotourism houses, farms, and similar infrastructures and organisations.

Dry or Low-Flow Toilets with Reused and/or Rainwater

In rural or peri-urban areas, where there is still no drainage and sanitation network for wastewater, dry or low-flow toilets with wastewater and/or rainwater (re)use may represent a technically and economically viable, more ecological and sustainable sanitation solution, enabling to contribute to circularity. In fact, the process may result in a compost that can be used as soil conditioner and/or fertilizer (as an alternative to chemical fertilizers), in addition to a significant reduction in the consumption of water from the public supply network.

Floating Islands with Vegetation/Constructed Wetlands

Floating islands with vegetation are platforms that float and support vegetation and other organisms that play a key role in water purification. This system is biological, self-sufficient and inspired by nature, being normally applied to ponds, lakes, rivers and other water bodies that suffer from some type of contamination, from domestic or industrial origin, for example. In this model of integral ecological sanitation, the use of ecological materials for the construction of floating islands is privileged, in particular cork of national origin, as a way of valuing endogenous resources and the territory.

Constructed wetlands are also biological systems based on natural processes for water and wastewater treatment [7]. Such systems comprise a basin filled with substrate to support plants and wide range of organisms, such bacterial and fungal communities [8]. Depending on the geography, typology and avalible area for process implementation, it is possible to choose between treatment via floating islands or constructed wetlands.

Environmental Education on Integral Ecological Sanitation

The innovative character of the integral ecological sanitation model, developed under the scope of ECOSAN project, presupposes the inclusion of social actors throughout the process, in order to promote training and a real appropriation of concepts based on practice. This approach to integral ecological sanitation implies the carrying out of structural actions (practical activities carried out in pilot units, of a demonstrative character) integrated with structuring actions (of education, participation and social mobilization).

The main goal was to contribute to the collaborative commitment of promoting an active citizenship in the field of sustainable development and construction of a low-carbon society, rational and efficient in the use of its resources, converging into models of sustainable conduct in all dimensions of human activity, as recommended in the National Strategy for Environmental Education (ENEA 2020), for the period 2017–2020. The following specific objectives can be highlighted:

(i) to promote ecological sanitation based on the adoption of technological solutions inspired by Nature, in particular, dry and/or low-flow toilets and floating islands with vegetation/constructed wetlands, and the recognition of their importance in the context of the circular economy and territory valorisation;
(ii) to develop actions aimed at empowering economic agents, in particular from the tourism, agriculture and industry sectors, and promoting a new attitude towards the valuation of the water resource, as well as the creation of value, more sustainable environmental policies and practices, that may lead to behavior change, individual and collective, as a way to contribute to the integral ecology.

The methodology underlying the accomplishment of such objectives encompasses several action-education activities, training and capacity-building actions, environmental awareness campaigns, conferences, seminars and exhibitions in order to promote the dissemination of knowledge. Teaching materials and a practical digital guide for the ecological sanitation were developed, an ideas competition was promoted and demonstration pilot units were constructed, namely “dry toilets” and “floating islands/constructed wetlands”.

These resources can be used in a pedagogical approach, as they enable educators to teach subjects like science, engineering, biology, chemistry and physics, capturing students’ attention, nurturing their creativity, and simultaneously building their academic skills and enabling them to meet educational goals.

The actions developed under the scope of the ECOSAN project, including the activities and the respective participants, are presented in Table 20.1.

Table 20.1 Actions and activities developed under the scope of ECOSAN project

Action type	Action	Activities	Participants
TA1. Awareness and environmental education	A1. Environmental awareness and education campaign on ecological sanitation	At1.1 Ideas competition: dry/low flow toilet design	Academic community (students, teachers and researchers)
		At1.2 Development of contents and dissemination materials	Academic community (students, teachers and researchers); technicians, project managers, economic agents, decision makers, public in general
		At1.3 Environmental awareness and education campaign	
TA2. Initiatives with a multiplier effect	A2. Education and training	At2.1 Benchmarking on dry toilets, with reuse of wastewater or rainwater	Students, teachers and researchers
		At2.2 Specialized training course	Students, teachers and researchers; senior technicians, local agents
TA3. Initiatives with active public participation	A3. Promotion of ecological sanitation systems	At3.1. Education-action activity on dry and low-flow toilets	Students, teachers and researchers; local community, local agents
		At3.2. Education-action activity on floating islands/plant beds for water treatment	
	A4. Reuse and efficient use of water	At4.1. Education-action activity on irrigation of green spaces	
TA4. Passive public participation	A5. Preparation of manual for comprehensive ecological sanitation	At5.1 Guide to good practices for integral ecological sanitation	Students, teachers and researchers; technicians, decision makers, rural tourism agents

Structuring Actions (of Education, Participation and Social Mobilization)

Awareness and Education Campaign on Integral Ecological Sanitation

This action included an ideas competition and the development of contents and pedagogical materials for dissemination, awareness and education on the integral ecological sanitation model. The target audience for such action involved academic communities (students, teachers and researchers), technicians and project managers of sanitation and irrigation systems, as well decision-makers, particularly in the tourism, agriculture and industry sectors.

The activities were planned and prepared by teachers and researchers from higher education institutions, combining specialised technical skills in the field of ecological sanitation and experts with recognised experience in dissemination and information activities, with national coverage through the Portal for Sustainable Construction (https://www.csustentavel.com/en/).

Ideas Competition: Dry or Low-Flow Toilet Design

The acceptance, by users, of dry and/or low-flow toilets involves the development of a product with an appealing design and competitive cost when compared to conventional equipment available on the market. The contribution to sustainability inherent to the integrated sustainable sanitation model is reinforced by the design of the product considering its entire life cycle, with a view to reducing environmental impacts, promoting eco-efficiency, through ecodesign. In this sense, an ideas competion was organised and carried out, emcompassing disclosure of the contest, analysis of applications, selection, disclosure of the winner and delivery of the award.

Development of Contents and Dissemination Materials

The innovative character of the integral ecological sanitation model requires communication with users, trainers, technicians, and decision makers on implicit concepts, advantages, limitations and opportunities. The adequacy of technical-scientific concepts to the target audience and the use of various communication channels facilitated the dissemination of the integral ecological sanitation model.

Considering the target audience of the environmental awareness and education campaign, several materials were developed, namely:

(i) Informative posters of the integral sustainable sanitation model to be disseminated in highschools and higher education institutions;
(ii) Flyers for dissemination of the integral sustainable sanitation model to be distributed among local agents, mainly in the tourism and agriculture economic sectors;

(iii) Informative flyers concerning the planned training-action activities, to be distributed among students, teachers and researchers;
(iv) Roll-up for the traveling exhibition in schools in the region;
(v) Digital pedagogical material to support education-action activities;
(vi) Short tutorial video for information and dissemination of the integral ecological sanitation model (https://www.youtube.com/watch?v=aaX2bknNSUc).

Environmental Awareness and Education Campaign

The Environmental Awareness and Education Campaign aimed at disseminating the integral ecological sanitation model, based on the ecotechnologies “dry and/or low-flow toilets” and “floating islands/constructed wetlands”, among several age groups and sectors of activity, including students and teachers (from highschools and higher education institutions), technicians, economic agents, decision makers, and the general public. It was intended to reduce the lack of information on options to be taken on ecological sanitation, addressing the associated concepts, good practices, limitations, environmental, social and economic benefits and opportunities for implementation. It was also aimed to contribute to changing the behavior of decision makers in the project and implementation of sanitation systems. Sensitive topics were addressed, such as climate change, the urban water cycle and efficient use of water, sustainable production and consumption, as well as the the potential of integral ecological sanitation models for territory valorisation and circular economy.

This action encompassed the following activities: (i) dissemination of contents and relevant information on integral ecological sanitation, based on “dry and/or low-flow toilets” and “floating islands/constructed wetlands” (short duration video-tutorials, presentations in digital format) on a Digital Platform—the Sustainable Construction Portal, which takes on the mission to help actual and future decision makers, building owners, architects, engineering and architecture students, among others, in choosing the most sustainable solutions, with awareness of the regeneration and restoration ability of the Biosphere; (ii) exhibitions in high schools and higher education institutions, using a model of the integral ecological sanitation; (iii) seminars in highschools under the theme “The power of plants to treat water—integral ecological sanitation” and a technical talk by Prof. Günter Langgregaber (BOKU University) under the theme “Development of treatment wetland in Austria” (CIIMAR, Portugal); and (iv) poster and oral presentations in national and international conferences [9, 10].

Education and Training

The training and qualification of educators, technicians and agents of the local economy in the design, implementation, operation and maintenance of ecological sanitation systems is considered as a key element in the adoption and dissemination of this model. Therefore, the methodology underlying the implementation of the ECOSAN project included benchmarking and advanced training.

Fig. 20.1 Education and training activities

Benchmarking on Dry and Low-Flow Toilets, with Reuse of Wastewater or Rainwater

Members of the project team participated in the DT 2018 Conference—6th International Dry Toylet Conference, promoted by the International Water Association (IWA) and Global Dry Toilet Association of Finland, under the theme Dry Toylet Goes Circular, which took take place from 22 to 24 august 2018, in Tampere, in Finland, with the objective of identifying dry and low-flow toilet systems and ecological sanitation models used in other countries and integrating technical-scientific knowledge in planned actions and activities [11].

Advanced Training Seminar

The target audience of the Advanced Training Seminar included highschool and higher education teachers, technicians in the field of sustainable construction (e.g., architects) and those involved in the design of sanitation systems (e.g., project offices), rural tourism agents, agricultural entrepreneurs (Fig. 20.1). The aim was to provide the participants with knowledge and skills regarding the integral ecological sanitation model, filling information gaps, training for its design, implementation, operation and maintenance. The opportunities for adding value through the implementation of this model were highlighted, in order to turn it into an alternative to be considered when making a decision and installation option, particularly in places where there is no wastewater sanitation network or connection to the sanitation network or is not technically and economically viable. The activity was concluded with a visit to a demonstration unit installed in a small organic farm (Biobrassica—Braga, Portugal).

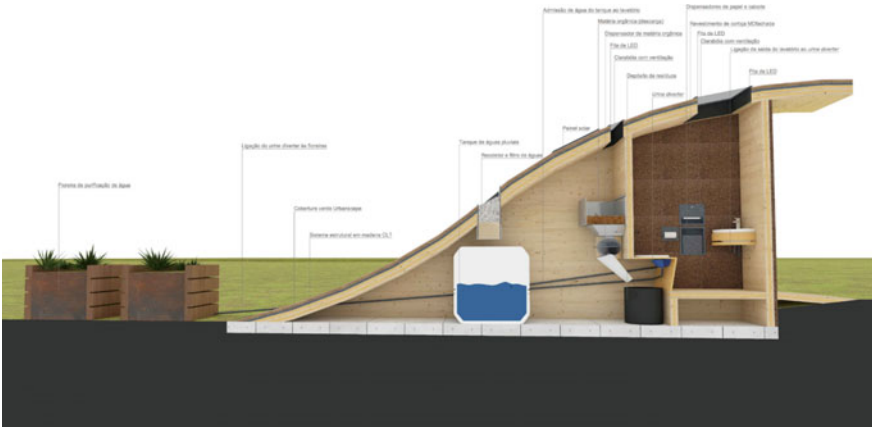

Fig. 20.2 Design of the demonstration unit of the ECOSAN dry toilet system

Structural Actions (Practical Activities Carried Out in Pilot Units, of a Demonstrative Character)

Promotion of Integral Ecological Sanitation Systems

The planned activities converged to raise awareness and education about dry and low-flow toilets with a view to reducing water consumption and pollution. The application models will be supported by ecological and sustainable solutions for dwellings located in places where there is no wastewater sanitation network or connection to the sanitation network or is not technically and economically viable.

Education-Action Activity on Dry and Low-Flow Toilets

With this activity, it was intended to promote the active involvement of the local community, students, teachers, reserchers and rural tourism agents in the identification of integral ecological sanitation solutions that enhance the circularity of the economy by valuing sanitation waste and wastewater at the domestic level, in the community and/or rural tourism units.

The activity included a theoretical component on the urban water cycle, as well as on measures that contribute to improving its efficiency with a view to the sustainability and resilience of territories. The practical component comprised design, materials selection, building and implementation, as well as a demonstration of the operation of a dry or/and low-flow toilet, highlighting the advantages in terms of reducing water consumption and contamination, recovery of waste and the related contribution to the circular economy (Fig. 20.2).

Fig. 20.3 Floating island with vegetation (School of Agriculture, Ponte de Lima, Portugal)

Education-Action Activity on Floating Islands and Constructed Wetlands for Water Treatment

In this activity, a general approach was made on the operation and application of floating islands and constructed wetlands to wastewater treatment, including basic concepts for their construction. These systems involve plants and microorganisms in water purification processes and have economic advantages over other biological systems. It was intended to provide an overview of its impact as a component of the integral ecological sanitation system and subsequent reuse of water. Theoretical and pactical sessions were carried out that encompassed: (i) introduction to biological systems (floating islands and constructed wetlands) with the purpose of improving water quality; (ii) characterization and application to wastewater treatment; (iii) System dimensioning (with a practical exercise); (iv) construction and installation of a floating island in a pond for domestic wastewater treatment, located in School of Agriculture of the Polytechnic Institute of Viana do Castelo—Portugal (Fig. 20.3); and (v) a technical visit to a constructed wetland located in Paço de Calheiros, Ponte de Lima, Portugal (Fig. 20.4).

Efficient (Re)use of Water

This action was planned with the purpose of disseminating good practices in the use of water and ecotechnologies for water and wastewater treatment with a view to its reuse, as a way to promote sustainable water management, the circular economy in the agricultural sector and rural tourism, the resilience and sustainability of communities.

Fig. 20.4 Constructed wetland (Paço de Calheiros, Ponte de Lima, Portugal)

Education-Action Activity on Intelligent Irrigation System in a Sustainable Garden

Green infrastructures for collective use, either public or private, contribute to human health and well-being, but also to the balance, protection and valorisation of the environment, the landscape and the natural heritage of the urban areas, particularly with regard to its role in regulating the hydrological cycle (e.g., preserving soil permeability and creating retention areas, preventing flooding in urban spaces), bioclimatic regulation in cities (e.g., reduction of temperature), improving air quality and biodiversity conservation [12].

With this activity, it was intended to provide the participants with knowledge and skills regarding: (i) assessment of the quality of treated wastewater for use in irrigation; (ii) choosing plants with similar water requirements, grouped into hydrozones; (iii) design of efficient irrigation systems and implementation of irrigation strategies; and (iv) assessment of the nutritional quality of the compost resulting from the composting of organic waste, including waste produced in dry or low-flow toilets.

The activity included: (i) a theoretical component on the benefits of green infrastructures for human health and environmental quality, criteria and parameters for the construction of a sustainable garden, with particular emphasis on efficient use of water; (ii) construction of an experimental demonstration unit of a green infrastructure with an inteligente irrigation system and monitoring of performance indicators (irrigation application uniformity and uniformity coefficient); the irrigation system was designed and managed to apply water as uniformly as possible to enhance crop production by providing equal access of water to crops. The irrigation application uniformity is a statistical property describing the distribution of water applied from an irrigation system. A uniformity coefficient of 100% (obtained with overlapping sprinklers) is indicative of absolutely uniform application. The needs of irrigation of each hydrozone were determined and soil moisture content was registered in order to assess the feasibility of the adopted irrigation strategy.

The target audience included the local community, students, teachers and researchers from highschools and higher education institutions, city council technicians with responsibility for green infrastructure management, rural tourism agentes, among others.

Preparation of a Good Practice Guide for Integral Ecological Sanitation

The ECOSAN project team developed and published a Good Practice Guide for Integral Ecological Sanitation with suggestions and guidelines to support the selection of sanitation systems, based on principles of circular economy and other sustainability criteria [13]. The contents of this guide are primarily focused on contextualizing what dry and low-flow toilets are, describing the main advantages and limitations, and diversity and flexibility of models. It was intended that this guide can be a tool that provides the basis for the installation of these toilets integrated in an ecological sanitation model, with generation of a product with added value, which is the compost. The wastewaters produced in these systems are treated by plant-based ecotechnologies—floating islands with vegetation or constructed wetlands—which promote the improvement of water quality so that it can be reused for irrigation of green infrastructures. The target audience include technicians, project managers, decision makers, rural tourism and other economic agents, students, teachers and researchers, the general public.

Medium and Short Term Impacts of the Environmental Education Programme for the ECOSAN Project Team and for the Target Audience

The following medium and short-term impacts of the project ECOSAN—Integral Ecological Sanitation were identified:

(i) For the ECOSAN project team:

the project team included teachers and researchers (PhD) from Polytechnic Institute of Viana do Castelo (IPVC, Portugal) and Interdisciplinary Centre of Marine and Environmental Research (CIIMAR, Portugal), with technical and scientific activity in biotechnology and environmental engineering. The environmental education programme developed under the scope of the ECOSAN project allowed training and production of educational resources to suport environmental education activities promoted, each year, by these institutions, as well as to support teaching activities; it also allowed to strengthen collaboration between the project partners, as well as with highschools, local agents in tourism, agriculture and industry economic sectors, and contribute to the collaborative commitment of promoting active citizenship in the field of sustainable development and building a rational and efficient society in the use of its resources, translated into models of sustainable conduct in all dimensions of human activity, as recommended in the National Strategy of Environmental Education (ENEA 2020), for the period 2017–2020.

(ii) For the target audience: capacity building of economic agents, in particular from the tourism, agriculture and industry sectors, and promotion of a new attitude towards the valorisation of the water resource, as well as the creation of value, more sustainable environmental policies and practices, promoting changes in individual and collective behaviors, as a way to contribute to the integral ecology and territory valorisation.

The continuity of the project ECOSAN—Integral Ecological Sanitation is ensured by the set of educational resources that were produced, namely the integral ecological sanitation system model (Fig. 20.2), integral ecological sanitation system tutorial video, posters, the Good Practice Guide for Integral Ecological Sanitation and the pilot demonstration units, which will also support several environmental education activities for sustainability involving the community, organized under the Eco-Schools Project (https://www.ecoschools.global/). Some activities have developed within the scope of Global Action Days (recently assumed by the Foundation for Environmental Education), which constitute an opportunity to promote and disseminate initiatives in favor of environmental sustainability, at national and international level. In addition, the pilot demonstration units will allow continued awareness-raising and training actions based on environmental monitoring.

Conclusion

The ECOSAN project allowed the identification of different technological solutions, inspired by Nature and by principles of circularity, which could integrate a comprehensive ecological sanitation model, in specific contexts, such as rural tourism houses or others located in places where the connection to the sanitation network is not technically or economically viable. Such ecotechnologies include dry or low-flow toilets, floating islands with vegetation and constructed wetlands for water treatment. Some of these solutions still lack technological development, so that they can be made available on the market in functional models, with attractive design and at a fair price, which may represent an opportunity for companies that, nowadays, are forced to reinvent its business models and production processes, in favor of environmental, economic and social sustainability.

It is clear that, if we assume the commitment and responsibility to contribute to sustainable and integral development, seeking to live in harmony with Nature, we may have to change habits or even deprive ourselves of something that we had until now taken for granted. But isn't that what we have been doing lately? Reality has forced us to make use of one of the most valuable characteristics of sapiens—our adaptability—and environmental education on integral ecological sanitation has a decisive role in this process.

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Chapter 21
Nature-Based Solutions for Environmental Education in the East Asian Context

Karen Araño Tagulao

Abstract Environmental education (EE) has long been practiced worldwide, while Nature-based solutions (NBS) is a relatively new concept. This chapter aims to provide an overview of the EE and NBS practices in East Asia and evaluate how these two valuable applications can be used concurrently. East Asia has a well developed environmental education (EE) programs and activities, both in formal and informal education. These ranges from developing green schools and campuses to establishing policies and acts. While EE has been actively practiced for decades in the region, the adoption of NBS to address environmental and societal challenges is limited. The educational benefits and opportunities from NBS are also lacking. Although there are some projects that can be classified as NBS, like the use of wetlands for wastewater treatment, they are not clearly categorized as one. These projects are also not integrated into environmental education programs. Considering this, the region should develop innovative environmental education programs for schools, universities and communities, that integrate NBS projects. Integrating the two together will boost the effectiveness of environmental education in raising environmental awareness and changing the environmental attitude and behavior of people, which will also help address societal issues.

Keywords Green schools · Green universities · Environmental awareness · Environmental policies/acts · Wetlands · Sponge cities

Introduction

Environmental education (EE) has a long history and has been practiced and implemented worldwide, including countries in East Asia. However, the concept of Nature-based solutions (NBS) is relatively new. Although there are past and on-going practices and projects that can be classified as NBS, they are not clearly categorized as one. As the concept of NBS becomes more significant, especially with addressing

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environmental and societal issues, its relationship with EE is also important to be explored.

An overview of the EE and NBS practices in the East Asian region including China, Macao SAR (Special Administrative Region), Hong Kong SAR, Taiwan, Japan and South Korea are presented in this chapter. As mentioned above, EE is being practiced in East Asia, but NBS is not fully defined as a concept in the region. Moreover, there are no obvious practices wherein NBS is utilized as a tool for enhancing EE or vice versa. Therefore, this chapter presents environmental education and NBS in East Asia independently with recommendations on how the current NBS initiatives can be integrated into environmental education in order to achieve education for sustainable development.

Environmental Education and Its Impact in East Asia

Environmental education and green universities are one of China's strategies in moving forward to an ecologically sound society [1]. This has been widely promoted to nurture sustainable development in higher education [2] and achieved through holistic strategies such as: "(1) educating future professionals and enhancing students skills and knowledge on sustainable development; (2) improving energy efficiency on campus; (3) shifting to renewably generated energy, food and other materials used on and off campuses; (4) increasing the university's social responsibility on environmental protection and resource economization; and (5) broadening the visions/knowledge/opportunities for action on all global issues environmental issues". The model (Fig. 21.1) of the Shenyang University in China, exemplifies a system that integrates various practices and innovation with research and education to achieve a sustainable green university.

It is however suggested [4] that it is more important for education to foster cultural change than just merely greening a university or integrating green perspective in the curriculum. Cultural change could be important to achieve behavioral and attitudinal change that can ultimately lead to a more sustainable lifestyle.

Environmental policy in China has been further accepted due to the lack of additional cost, hence, no resistance because of economic restraints [5]. It has been found that less wealthy jurisdictions have the tendency to develop more ambitious environmental policies. The study also suggests that implementing environmental education into compulsory school years, students can learn the routines of a green lifestyle. China has also established the Centers for Environmental Education and Communication which furthered efforts in environmental education through making media greener, creating television lectures for remote environmental training, creating outdoor advertisements for environmental protection and through multinational efforts such as the Tripartite (China-Japan-Korea) Environmental Education Network (TEEN) [6].

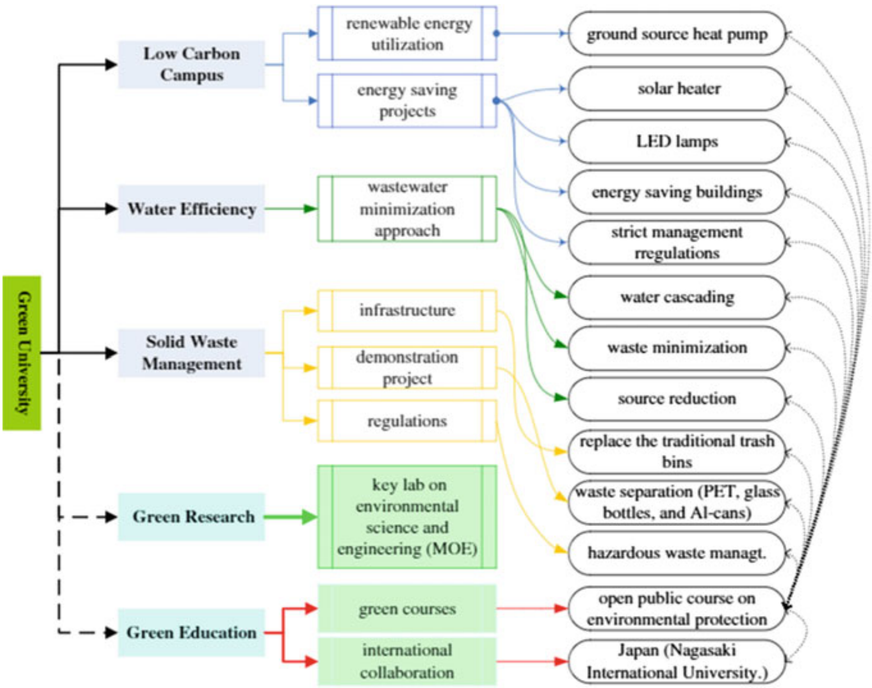

Fig. 21.1 Integrated strategies of Shenyang University's green campus in China [3]

A study from thirty provinces in China showed that increased higher education and environmental education (together with foreign direct investment) is beneficial to lowering CO_2 concentrations [7]. The study suggests that governments should "extend social and financial support for curricula, programs, collaborations, or other academic activities aimed at reducing emissions and preserving energy and resources". It also recommends the development of more green campuses and pushing forward green initiatives/projects.

Japan, Korea and Taiwan have similar investments in environmental education, however, there are more concerns over the difficulty in raising awareness about EE in Taiwan and Korea [8]. All of them introduced EE as a concept to combat the rising environmental issues, such as pollution due to rapid industrialization and resource exploitation. Japan started earlier, in the 1950s, followed by Taiwan in the 1980s and South Korea in the 1990s [8]. Japan introduced the Act on the Promotion of Environmental Conservation Activities through Environmental Education from 2003 (revised in 2011) which facilitated the development of government EE plans and collaborations between public and private sectors to promote EE [8]. Similarly, Taiwan introduced the Environmental Education Act in 2011, which funded further EE certified institutions, facilities and personnel. This legislation requires at least 4 h of EE activities for citizens each year, resulting in EE flourished cities [8].

South Korea also established the EE promotion Act in 2008 which resulted in the institutionalization of social EE [8].

Japan implements EE in schools although there is no separate subject specifically for EE. It is taught as both a component of various subjects and a “non-subject” offering. In elementary, junior high, and high schools, EE is mainly integrated as part of other subjects such as social studies, science, home economics, and integrated studies. Japan’s latest curriculum focuses more on fostering students for sustainable society and encourages educational activities in collaboration with residents, the government and private sectors and local governments, which reflects a transformation to a curriculum more open to society [8].

Japan has also been focusing on a form of EE known as Conservation Education as well as Education for Sustainable Development [9]. It has implemented EE through more direct methods such as hands-on learning, through restoration of agricultural wetlands, as was the case in the wetlands of Kabukuri-numa. Local students, citizens and farmers participated in the restoration of these wetlands, learning of the species richness in the area, the importance of environmentally sound farming and the necessity of coexistence between farmers and waterfowl [9]. In Yokohama City, 300 dragonfly ponds were restored through partnerships of university students, local governments and NGOs [9]. This direct method of EE allowed for further understanding of local environmental issues and raised environmental awareness. On the other hand, the effects of EE in Japan have also been found to be quite limited, resulting in superficial awareness of issues with limited knowledge regarding the complexity of environmental issues [10]. Japan’s Education for Nature Conservation (ENC) has made efforts to encourage people to assist in nature conservation efforts and is a milestone in the implementation of EE in Japan. However, ENC has failed to factor in the social, political and ideological aspects of environmental problems. It is suggested that for EE to fully succeed in Japan, it should be implemented as a core element of schooling [10].

South Korea’s National Curriculum implements EE both as a subject and in a non-subject manner. Elementary schools teach EE using a distributed approach as part of other courses. In junior high and high schools, the distributed approach is still used, however independent courses called Environment, focusing on EE are offered (albeit with low adoption rates). These courses teach harmonious life in the earth’s ecosystems, solving environmental problems faced by mankind, climate change and decreases in biodiversity, and realizing a sustainable society. EE is also offered in a non-subject manner through “creative experience activities” as part of “free semester systems” at high schools and after school activities which are mostly implemented through volunteer work and club activities, although also implemented through autonomous education and career education [11].

In terms of higher education, South Korea offers degree programs for EE school teacher training that combine pedagogy, environmental engineering, and science, but emphasis on philosophies, concepts, and methods specific to EE is limited. The Korean Association for Green Campus Initiative (KAGCI) was established in 2008 and has played a significant role in facilitating EE at various universities since its establishment. It initiated the introduction of good practices and facilitated research which produced many green campuses nationwide. More universities followed suit, especially following the Paris Climate Change Accords and UNSDGs [8].

In recent years Taiwan has implemented the Green School Partnership Program (GPPT) which is "based on the idea of whole-school approaches to sustainability and is characterized by a reward and evaluation system" [12]. However, it was found there was only a significant effect in the environmental attitude of 12th graders, whereas there was limited effect compared to non-GPPT schools. However, as mentioned in the beginning, in 2011 Taiwan legislated the Environmental Education Act which requires employees in the public sector and students to participate in EE programs for 4 h per year [13]. Studies of this legislation have found conflicting results, with some improvements on students' environmental attitude whereas other studies have found limited success. Studies have also been conducted on sixth graders in eastern Taiwan that conclude students' environmental knowledge cannot be promoted in the absence of structured programs and teaching strategies, even with lively activities such as field trips [14]. Hence, it is suggested that well-structured lesson plans involving role play and games may be beneficial to the retention of environmental knowledge. Despite this, it may not be applicable to the whole of Taiwan due to testing of a single region in the related study.

Just like the previously mentioned places, EE initiatives in Hong Kong goes a long way back. Their "Guidelines on Environmental Education in Schools" was issued in 1992 of which the Education Department has recommended a cross-curricular approach to nourish students environmental awareness and behavior allowing them to become environmentally responsible citizens long term [15]. Schools have adopted a holistic approach to EE as recommended by the Curriculum Development Council through implementing EE both in a formal and informal setting. Other than classes themselves, EE is also a core component of assemblies and extra-curricular activities, such as the various activities set up by Community Youth Clubs (CYC) and Green Clubs to promote environmental conservation. Hong Kong also has the Schools Environmental Award Scheme (SEAS) cum Student Environmental Protection Ambassador Scheme (SEPAS) program which is aimed at developing students' sense of responsibility regarding the environment. To further such efforts in EE, the School Waste Paper Recycling Scheme has been implemented since 1994 to reinforce environmental protection through the 3 Rs of reduce, reuse, recycle [15].

The small SAR territory, Macao, has also been increasingly incorporating EE in the school curriculum. Schools are required to carry out a curriculum reform based on a government prescribed framework [16] with their own characteristics and education. Students acquire basic knowledge and attitude towards the environment when they complete the 15-year education. Infants are cultivated with basic concept of environmental protection. In the primary, they aim to nurture this by showing curiosity and interest in the nature and show care for the environmental issues faced by human beings. In junior secondary, they learn the ecological environment in Macao and their protective measures and in senior secondary, they master the concept of sustainable development and are able to explore the current situation of the ecological environment. Even though the government provides a framework for the school, delivery and implementation of environment related content depend on the schools, and so the students' learning experiences may differ.

Nature-Based Solution Practices in East Asia

Despite some success, adoption of NBS is generally limited in East Asia [17]. Fast growing cities require planning NBS to be implemented as opposed to retrofitting cities with NBS which is far more expensive. Cultural differences also make it difficult to standardize adoption of NBS. Educational programs for engineers in NBS must require high level cognitive skills as NBS projects require complementary skills not typical in traditional settings [18].

In China, various forms of NBS have been implemented. One example is a riverfront planning in Wusheng County, Sichuan Province, that is intended to as a multipurpose NBS, one that mitigates negative environmental impacts and protects the wilderness [19]. Usually in the Chinese system, a schematic plan is required to provide general guidance and prioritize projects for implementation. Nature based solutions can also be used for urban regeneration following natural disasters, such as in Chongqing [20]. Given the increased urbanization of Chongqing further into the mountains, NBS can promote urban regeneration and reduction of damage due to natural disasters. "While these measures are effective in understanding how natural disasters impact on urban regeneration, further research is required to fully understand these complex processes" [20]. Moreover, in 2013, China launched the "Sponge City Program" (SCP) as a way to develop solutions to manage urban flood risk, purify stormwater and provide water storage opportunities for future use [21]."The SCP aims to restore the urban hydro-system using eco-friendly measures" [21]. This study on the SCP discusses the implementation of "Green + Grey" infrastructure where an NBS is capable of addressing multiple issues at the same time, which is a more efficient way of using NBS.

Following the 2011 Earthquake in Japan, NBS has been used as part of recovery planning in Futaba County, Fukushima Prefecture, Japan [22]. In particular, NBS is essential for resilience against future tsunamis and can act as an educational site as well as a memorial site to remember the tragedy of the 2011 Earthquake and Tsunami. However, this study has acknowledged that post-disaster implementation of NBS is not always possible. Nevertheless, Futaba County acts as an effective model for the implementation of NBS post-disaster.

In Korea, NBS has been used as an environmental purification method, specifically the use of riparian forests with poplar trees for ecological watershed management [23]. This study found that through the use of riparian forests, there was a lower total nitrogen and total phosphorus contents in surrounding areas of the forest compared to those without NBS. The Seoul Metropolitan Government has also implemented the "Making a Walkable City" campaign as part of 2016 redevelopment which involves the use of pocket parks to improve the microclimate [24]. In addition, drastic steps have been taken in Seoul to reduce pollution and curb the reliance on fossil fuels [25]. In the 1960s residents of the area where Cheonggyecheon River was situated were more than twice as likely to suffer from respiratory diseases. To combat this issue, the restoration of Cheonggyecheon River was conducted in 2003 and completed in 2005, decreasing small particle air pollution by 35% and increasing overall biodiversity by 639% [25].

An example in Taiwan is the commissioned Kaoping River Rail Bridge Constructed Wetland which acts as a non-point source (NPS) pollutant remover, wastewater treatment, wildlife habitat, recreational and educational site [26]. This resulted in the significant removal of total coliforms (TC), biochemical oxygen demand (BOD), and nutrients (e.g., total nitrogen, total phosphorus) by the constructed wetland system. This implementation of NBS has increased green areas along riversides, offered more water assessable eco-ponds and eco-gardens for the public as well as a way to rehabilitate the natural ecosystem. Another study reviewed the effects of the Kaoping River Rail Bridge Constructed Wetland from the perspective of water quality improvement [27], which showed similar removal rates of TC, BOD, and nutrients by the constructed wetland system. However, high concentrations of metals were found in the area, meaning sediments should be excavated periodically.

The SAR territories, Hong Kong and Macao, also have several NBS related projects and infrastructures. Hong Kong has implemented the Greening Master Plan in response to a study that the benefits of greening the urban environment and promoting livability and a consultancy study on sustainable building design [17]. Constructed wetlands are also utilized in Hong Kong for removing nutrients and toxic pollutants from wastewater [28], storm water management [29] and other purposes. In Macao, NBS related projects such as wetlands (e.g., mangroves) restoration and management and urban gardens, are established or being developed, but similar to other countries/territories, these are not clearly defined or categorized as NBS. One relevant example though is an on-going project by one of the higher education institutions, investigating the role of wetlands (mangroves) for water pollution mitigation and climate change mitigation and adaptation [30].

Integration of Nature-Based Solutions in Environmental Education

Environmental education and NBS have a similar goal in addressing environmental and societal challenges and integrating the two together will boost the effectiveness of EE in raising environmental awareness and changing the environmental attitude and behavior of people, which will also help address societal issues (Fig. 21.2).

Based on the reviewed EE practices and NBS projects, only a few examples, e.g. Japan's wetland restoration for conservation education [9] and Macao's NBS project that involve schools and community outreach [30], demonstrate integration of NBS into EE.

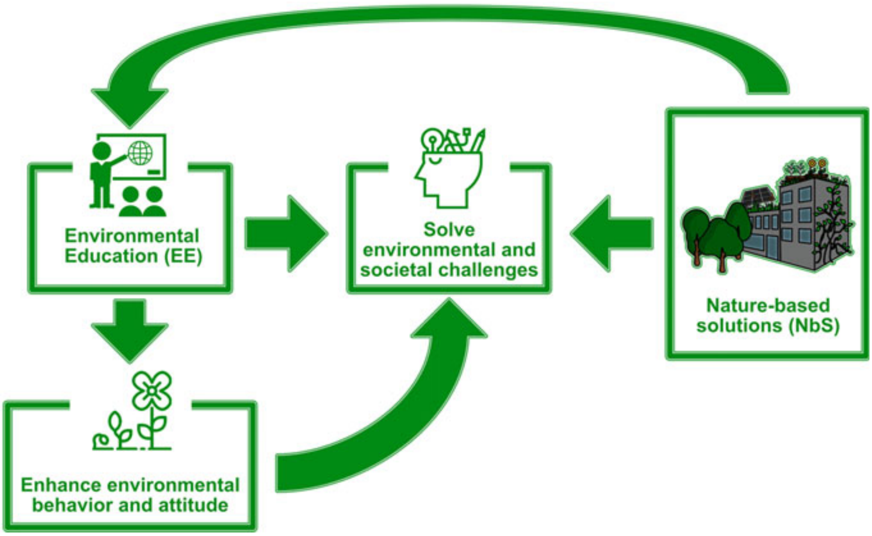

Fig. 21.2 A model of how nature-based solutions can be integrated into environmental education to address environmental and societal challenges

Conclusions and Recommendations

Most of East Asia have well developed EE programs that are integrated in formal education, in the schools (primary to secondary) and universities (higher education). Moreover, informal EE related programs are offered and implemented for communities. Many places in East Asia also invest in NBS to address environmental issues. However, the educational benefits or opportunities from NBS remain lacking and undeveloped in this region of the world. Programs around NBS are not integrated into formal and informal education. Although some activities, like green schools and green universities, do implement innovations and practices that are considered as NBS, these are not directly integrated into the education system. Related to this, the following ideas are recommended:

- Develop innovative environmental educational programs that include NBS, utilizing existing NBS projects in cities
- Develop new NBS demonstration projects that integrate educational aspects
- Integrate NBS concepts and practical training in Science and Environment subjects taught in schools and universities
- Provide opportunities for learning about NBS in the form of workshops/seminars, life-long learning courses, and practical integration, to raise awareness among members of the public/communities (individuals, families, groups)
- Reinforce additional support from the government, NGOs and the general public/community.

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Chapter 22
Decarbonizing the European Energy Sector: Frameworks, Examples and How Education Plays a Key Role

Manuela Prieler, Karin Fazeni-Fraisl, Johannes Lindorfer, Darja Markova, and David C. Finger

Abstract Traditional engineering courses at leading universities still frequently focus on specific fields such as the design and building of machines, structures, and other items, including bridges, tunnels, roads, vehicles, and buildings. Ongoing research reveals that present environmental challenges require an interdisciplinary engineering approach, accounting for system analytical aspects. In particular, the energy transition to renewable energy production requires the assessment of technical, social, environmental and economic aspects. However, know-how generated from ongoing research is not always integrated into the teaching curriculum of higher education institutions. This chapter provides an overview of past and ongoing collaborations through research projects focusing on decarbonizing the energy sector in Europe and the importance of environmental education to promote and implement sustainable energy technologies. We outline how innovative technologies and management schemes could be implemented into the curriculum of engineering classes, summer schools, and student projects. We conclude the chapter by outlining the importance of environmental education for an energy transition that embraces a climate-neutral European Continent.

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Introduction

The current use of resources is jeopardizing the planetary boundary limits to a point that we might reach irreversible damage to the environment and subsequently to human societies [1]. The emission of greenhouse gases and consequential climate change is one of the most imminent threats [2]. The energy sector contributes about two-thirds to the global warming potential and accordingly, is responsible for a key impact [3]. Decarbonisation is a major step and essential for sustainable development. Hence, sustainable generation of energy based on renewable and decarbonized energy resources is of central importance.

As early as 1992, within the framework of the so-called Earth Summit, Article 36 of the Agenda 21 passed the action reorienting education towards sustainable development [4]. At the follow-up conference in Johannesburg in the year 2002, a decade of education for sustainable development was suggested as part of the implementation plan of the World Summit for Sustainable Development [5].

The United Nations adopted the 2030 Agenda for Sustainable Development in September 2015 [6]. The agenda identifies 17 Sustainable Development Goals (SDGs) and 169 targets to ensure and promote worldwide more sustainable development. It is the turn of the UN member states to implement this agenda.

The Agenda's 2030 Goal 7—Ensure access to affordable, reliable, sustainable and modern energy for all—is central for the aspired decarbonisation of the energy sector. The goal originally includes five targets:

- 7.1 By 2030, ensure universal access to affordable, reliable, and modern energy services
- 7.2 By 2030, increase substantially the share of renewable energy in the global energy mix
- 7.3 By 2030, double the global rate of improvement in energy efficiency
- 7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency, and advanced and cleaner fossil-fuel technology and promote investment in energy infrastructure and clean energy technology
- 7.b By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular, least developed countries, small island developing states and landlocked developing countries, in accordance with their respective programmes of support.

Education is addressed in the Agenda 2030 by SDG 4 "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all". Especially target 4.7 addresses the importance of decarbonisation and emphasises the focus on sustainable development: "By 2030, ensure that all learners acquire the 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". Education for sustainable development and sustainable lifestyle is on one hand the goal and on the other hand way for reaching it.

Central tasks are set by UNESCO. Education for sustainable development is beside global citizenship education named as a key program of the UNESCO Forum [7]. It is guided by the vision of "reorient education and learning so that everyone has the opportunity to acquire the knowledge, skills, values and attitudes that empower them to contribute to sustainable development" [8]. Four main fields for action were identified: (i) advancing policy, (ii) transformation of learning and teaching environments, (iii) building capacities of educators and trainers, (iv) empowering and mobilizing youth and accelerating sustainable solutions at the local level.

In the context of decarbonisation, knowledge, as well as environmental awareness, are essential for the transformation. Climate change and the need for decarbonisation are a growing concern in most societies; various studies demonstrated the worries of the people in context with climate change and the rising number and of associated environmental risks like floods, droughts, fires, storms or sea-level rise [9]. Prominent examples that climate change became more relevant for the public in recent years are the demonstrations and school strikes for climate protection, which started all over the globe—the Fridays For Future movement [10].

Knowledge is a key element for the protection of the environment [11]. The implementation of an adequate environmental education system is an effective way in this context. It is therefore elementary to raise awareness and conscience, and provide information about environmental problems to students of all levels [12].

Since the 1980s larger universities have incorporated environmental engineering programmes in their curriculum and some cases have established entire faculties or institutes to promote environmental education [11]. A prominent definition for environmental education is given by Stapp et al. [13]: "Environmental education is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems and motivated to work toward their solution." Environmental engineering is part of engineering, where the environment is protected, the health of living organisms is improved and the quality of the environment is preserved [14]. Accordingly, environmental engineering is part of environmental education and distinguishes itself from traditional engineering by incorporating multiple disciplines, such as chemistry, biology, ecology, geology, hydraulics, hydrology, microbiology, and mathematics, with the aim to protect the environment.

Unfortunately, many traditional engineering study programs still lack adequate environmental engineering courses. In order to meet the challenges of decarbonizing the energy sector a holistic system analytical approach is needed, which is frequently missing in traditional engineering lectures. This approach requires a cross-sectoral and interdisciplinary concept, covering a wide array of modern engineering aspects.

The following sections outline the decarbonization of the energy sector and highlight the importance of implanting holistic system thinking into the educational curriculum. Section "Framework and Scenarios of Decarbonizing Energy Systems" introduces the concepts for decarbonization, Sect. "Renewable Hydrogen as an Enabler for Deep Decarbonisation—Current Insights from Austria" adds a more practical perspective showing successful project implementation and Sect. "Measuring the Transition: Assessment Options for Ecological, Economic, and Social Impacts" gives insights into the methodology for the assessment of technologies necessary to mitigate climate change. The chapter concludes with Sect. "From Scientific Research to Realisation and Implementation in Education", where research concepts are linked to current education curricula and needs to adapt the education system are identified and highlighted.

Framework and Scenarios of Decarbonizing Energy Systems

At the G7 summit at Schloss Elmau, Germany, in 2015 the leaders of the world's seven largest economies agreed that the entire global economy should decarbonize and become completely CO_2-neutral by 2100 [15].This plan requires very rapid decarbonization [16].

The term decarbonization refers to the renunciation from carbon in order to avoid anthropogenic CO_2 emissions. The combustion of coal, natural gas or oil releases CO_2, among other gases, which causes the dreaded greenhouse effect, and ultimately the warming of the earth's climate [17]. Technological counteracting implies replacing CO_2-intensive processes with low-CO_2 or CO_2-free processes. The efforts of reducing greenhouse gases can be classified into (i) decarbonization or (ii) defossilization [18]. For decarbonization, all CO_2-emitting technologies would have to be replaced, defossilization denotes the phase-out of the use of fossil fuel-based resources.

The term climate neutrality goes further. It describes the state in which the effects of all anthropogenic and natural factors influencing temperature compensate each other so that the global warming effect is halted or potentially even reversed. In addition to greenhouse gas emissions, the relevant factors include, for example, changes in air pollution (e.g., from soot, sulphur dioxide (SO_2), or particulate matter), cloud cover (height and type of clouds), and the Earth's surface reflectivity (albedo) [19]. The Earth's atmosphere is global, and local greenhouse gas emissions have a global climate impact. Therefore, climate neutrality must also be pursued as a global goal with joint international efforts and global approaches to solutions. The potential for removing CO_2 from the atmosphere also varies greatly from country to country and region to region. Some countries would have to mobilize the potential of other countries in order to achieve climate neutrality. Climate neutrality can only be achieved with a holistic approach and inclusive energy and economic system that accounts also for the costs of environmental impacts [20]. To this end, studies identify sector-specific clusters of cross-sectoral requirements for climate-neutral energy sources such as renewable electricity and climate-neutral gaseous and liquid energy sources and raw materials [21].

The suitable measures available for decarbonization strongly depend on the sector. In transport, it is most cost-effective to electrify large parts of the public transport, passenger car fleet, light commercial vehicles, and tractor units by promoting a balanced mix of Battery Electric Vehicle (BEV) and Plug-in Hybrid Electric Vehicle (PHEV) [22]. Households, on the other hand, act much more sluggishly than the transport sector. Accordingly, measures that will work in 2050 must be implemented today. One important measure in this regard is the use of solar heat collectors, residual industrial heat for district heating, geothermal heating, and electric heat pumps, to name just the most prominent. An increase of electrification (switching from carbon-based to electricity-based processes) implies additional challenges for the electricity supply, especially regarding load flexibilization and storage capacities. In the energy-intensive industrial sectors, various measures such as energy efficiency and electrification can help reduce emissions. Furthermore, CO_2 capture and storage can be used to complement efforts to reduce emissions. Usually the CO_2 is captured from large point sources, such as a chemical plant or biomass power plant, and then stored in an underground geological formation. Energy efficiency and electrification also play an important role in the heterogeneous sector for trade, commerce, services. The supply sector influences indirect emissions based on the carbon intensity of the energy mix. Here, the expansion of renewable energies is most important, which means, for example, the full utilization of wind power potential. In addition, technologies for the provision of electricity-based fuels can substitute part of the fossil fuel imports by coupling with the electricity sector and at the same time provide flexibility for the energy system [23].

However, there will still be areas in the future where electrification is very cost-intensive, e.g. air and shipping traffic. In industry, it can also partly make more sense to change only the energy source and not the entire technology. When this change of energy source takes place, so-called green fuels replace fossil fuels [24]. Green fuels refer to all solid, liquid and gaseous fuels produced from biomass, renewable electricity or a combination of both. This means that green fuels are CO_2-neutral over their life cycle, as they absorb CO_2 from the air during the growth or production phase and release it again during combustion [25]. Strictly speaking, however, it is not possible to speak of decarbonization in this case, since CO_2 is emitted during energy provision. The term "defossilization" would be more appropriate here, because the fuels used no longer come from fossil sources. Nevertheless, the move away from fossil fuels has entered the discourse as "decarbonization," so that this term usually includes renewable fuels that are actually still carbon-based.

Decarbonization: Measures until 2050

For Europe to become a climate-neutral continent by 2050 at the latest, the energy-intensive sectors of cement, steel and chemicals, in particular, must rapidly switch to climate-neutral energy sources and raw materials [26, 27]. This major goal is ambitious especially related to the timeline. But what are possible ways to achieve the goal? The International Energy Agency (IEA) developed a pathway to building a

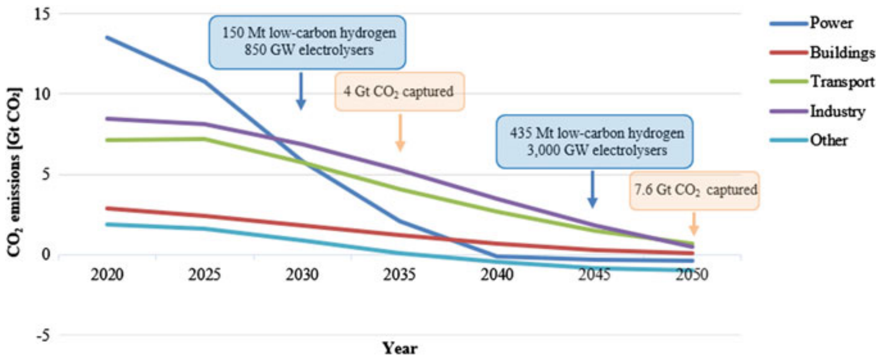

Fig. 22.1 CO_2 emissions by sector in the IEA Net Zero by 2050 scenario in giga tonnes [Gt CO_2] and key milestones in the pathway to net-zero (reproduced from IEA 2021 [28])

global energy sector with net-zero emissions in 2050, key milestones are represented in Fig. 22.1 and summarized in Table 22.1.

In May 2021 the International Energy Agency (IEA) postulated a net-zero carbon emission supported by all major industrialized countries responsible for 70% of global CO_2 emissions [28]. The strategy must promote investments for rapid conversion to CO_2-free technologies and create new markets for sustainable products in order to achieve climate neutrality in an accelerated time frame. There is significant potential for savings in three sectors in particular:

Industry sector

Two-thirds of industrial emissions are energy-related and could in principle be avoided by using energy sources that are climate neutral, so a profound change in processes can greatly reduce process-related emissions [29]. However, emissions cannot be fully prevented: Climate-neutral substitute routes are not available for all products, or residual emissions will occur at some points. These would have to be compensated or valorised in Carbon Capture and Utilization (CCU) approaches elsewhere [30].

Energy sector

Further emissions can be reduced if electricity is increasingly sourced from renewable energies. In this context, sector coupling represents a promising solution approach and in this context, new processes such as flexible biogas plants, waste heat utilization, heat from electricity, the power-to-gas approach, and increasing electromobility can help to improve the values even further in the future [31]. It takes an increase in the rate of renovation to bring about full or extensive coverage of the heating and hot water needs of the building stock by renewable energy [32].

Table 22.1 Key milestones in the pathway to net-zero for the global energy sector (reproduced from IEA 2021 [28])

Year	Milestone
2021	No new unabated coal plants approved for development
	No new oil and gas field approved for development; no new coal mines or mines extension
2025	No new sales of fossil fuel boilers
2030	Universal energy assess
	All new buildings are zero-carbon-ready
	60% of global car sales are electric
	Most new clean technologies in heavy industry demonstrated at scale
	1,020 GW annual solar and wind additions
	Phase out of unabated coal in advanced economies
2035	Most appliances and cooling systems sold are best in class
	50% of heavy truck sales are electric
	No new ICE car sales
	All industrial electric motor sales are best in class
	Overall net-zero emissions electricity in advanced economies
2040	50% of existing buildings retrofitted to zero-carbon ready levels
	50% of fuels used in aviation are low-emissions
	Around 90% of existing capacity in heavy industries reaches end of investment cycles
	Net-zero emissions electricity globally
	Phase-out of all unabated coal and oil power plants
2045	50% of heating demand met by heat pumps
2050	More than 85% of buildings are zero-carbon ready
	More than 90% of heavy industrial production is low-emissions
	Almost 70% of electricity generation globally from solar PV and wind

Transport sector

The transport sector has been relying almost entirely on fossil fuels making a transition towards renewable carbon-free sources challenging. In order to change this status quo, the main levers for effective measures are traffic reduction, route shortening, compliance with emission limits, and changing propulsion systems and energy sources. Other concrete measures for the mobility transition include [33]:

- Shift individual motorized traffic to environmentally friendly modes of transport (e.g. public transport, cycling infrastructures, sharing services etc.)
- Reduce freight transport, a shift from truck traffic to rail
- Traffic-avoiding urban and regional planning
- Rapid and widespread electrification of vehicles

- Promoting virtual mobility
- Convert remaining combustion engines to synthetic fuels (e.g., air traffic and heavy goods traffic which cannot be electrified).

The solution to the challenge is a system analytical approach. In order to achieve decarbonization additional measures and processes are needed to overcome the associated challenges [34]. Not only in the three sectors presented, but everywhere where there is potential for savings through rethinking and new processes. Decarbonization is a task for business, industry, politics, and for all the society. A stable regulatory framework must create an attractive market environment for climate-neutral solutions, products, and processes, in which they maintain economic viability and competitiveness over emissions-based alternatives while retaining comparable other attributes.

Climate neutrality needs a holistic approach, accounting also for the social sector and the education sector as a nucleus for necessary measures and strong governance to reduce the uncertainties associated with the transformation [35].The social challenges of the energy transition have accompanied this transformation almost from the very beginning, making it more important to actively involve people, to communicate benefits and challenges to them transparently, and to enable individual design options and active participation—through direct economic as well as non-economic participation [36].

Complementary options are needed in all conceivable transformation pathways to increase or actively undertake the removal of CO_2 from the atmosphere. Sustainable greenhouse gas sinks are needed to achieve the climate targets. In addition to natural CO_2 sinks (e.g., peatlands, soils, forests and oceans), these include technical methods for removing atmospheric CO_2 (carbon dioxide removal, CDR). This requires a development push in negative emission technologies (NET) [37, 38].

Studies in the field [39, 40] showed that a successful energy transition requires a three-pillar strategy: (i) increasing energy efficiency, (ii) greater direct use of renewable primary energy (renewable electricity and biogenic energy sources), and (iii) the provision of renewably produced gaseous and liquid energy sources and raw materials. To achieve climate neutrality, a fourth pillar must be added to this strategy: active CO_2 mitigation from point sources as well as from the atmosphere [41].

The implementation will require access to a wide range of expertise to support the design and implementation of decarbonisation and climate resilience plans, representing new knowledge on practices not currently used. The growing need will require a similarly growing pool of experienced and trained people available to provide this expert advice and abilities. Growing access to appropriately skilled and equipped experts presents economic opportunities to the society Education and engagement can assist in a rapidly growing sector, sharing of skills is important, to ensure that implementations of the required measures are based on the most practical, cost-effective and reliable technology and systems to meet future needs of the decarbonisation [42].

Renewable Hydrogen as an Enabler for Deep Decarbonisation—Current Insights from Austria

As drawn out in Sect. "Framework and Scenarios of Decarbonizing Energy Systems", the industry will play a key role in decarbonization. Accordingly, this section focuses on the potentials of renewable hydrogen, which is produced via electrolysis by using green electricity for the enhancement of decarbonising industry, particularly where electrification is not possible. There are many options for use of green hydrogen in the steel industry, chemical industry, refineries and other industry sectors. The global annual demand for hydrogen in the industry has increased constantly over the last decades and achieved over 70 Mt in 2018 (see Fig. 22.2).

In the following, we focus on case studies of green hydrogen use in Austria, since Austria has a highly developed industrial sector, a well-developed renewable electricity grid with over 75% of renewable electricity share, and an ambitious policy the decarbonize the entire energy sector by 2030.

In Austria, the hydrogen demand of the industry sector could amount up to 1,023–3,479 GWh/a if the entire sector gets decarbonized [44]. These estimates are in line with the hydrogen demand in the European industry sector [45].

Austrian industry is the second-largest CO_2-emissions emitter in the country, just behind the transport sector. Most of the CO_2 emissions come from intensive steel production, refineries, and chemical industries, there is a big potential to reduce emissions by replacing fossil fuels with green hydrogen. In the last years through nationally funded programs, some power-to-gas projects driven by industry have started and in the near future operation of electrolysers and demonstration of hydrogen production and use will be possible. The projects, which will be described further may serve as illustrative examples to gain new knowledge for the students as well as to increase the social acceptance of the general public.

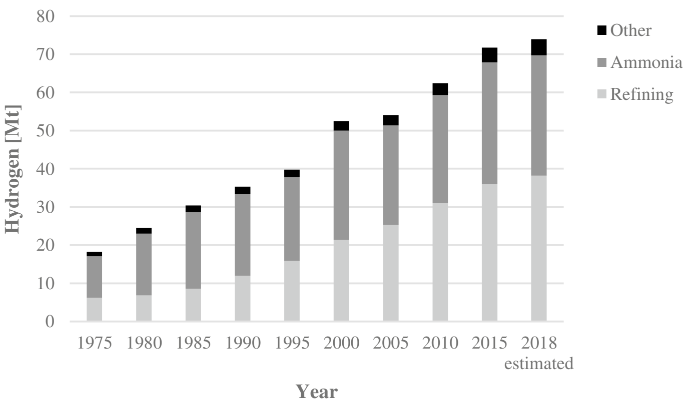

Fig. 22.2 Global demand for pure hydrogen by industrial customer 1975–2018 in million tonnes [Mt] (reproduced from IEA 2019 [43])

One of these projects is H2Pioneer [46]—"Pave the way for green hydrogen for early adopters in the light industry", whereon the possible use of green hydrogen in the industry will be demonstrated. Due to strict requirements on the purity of the hydrogen (more than 80 vol%) large quantities of liquefied hydrogen produced from fossil sources are currently imported from Germany or Netherlands. During the last years the semiconductor industry has been growing very fast, resulting in a significant increase of highly pure hydrogen demand. For example, the Infineon Austria AG, located near the village Villach in southern Austria, produces semiconductors and uses hydrogen in the production process as carrier gas. After use, hydrogen, highly diluted, is emitted into the atmosphere.

The aim of the H2Pioneer project is to demonstrate the on-site production of green hydrogen ensuring its compatibility with high standards needed for the industry.

There are two innovative parts of the project: (i) implementation and operation of an onsite Polymer Electrolyte Membrane (PEM) electrolysis plant and the purification system to ensure 8.0 quality of hydrogen and (ii) evaluation of reuse options of the hydrogen-rich exhaust gas (recycling, back to process or energetic use).

Thus, the overarching goal of H2Pioneer is to establish an onsite-production of green hydrogen to meet the expected increasing demand of the semiconductor industry. Hydrogen will be produced round the clock (7/24) in the highest quality according to the economic and ecological requirements of the "green industry." The first innovation is the implementation of the onsite PEM electrolysis plant and the purification process to ensure 8.0 quality of hydrogen. The second substantial innovation is the conception and evaluation of reutilization strategies of the exhaust hydrogen within a "green hydrogen cycle" (recycling, back to process or energetic use).

As refinery is one of the biggest users of hydrogen in the world, using renewable hydrogen instead of fossil hydrogen would allow the overall emissions reduction in that particular industry. The nationally funded project UpHy—"Upscaling of green hydrogen for mobility and industry" [47] plans to produce green hydrogen near the refinery plant and use the hydrogen both for refinery and mobility, whereas the share of hydrogen in mobility would increase according to the increasing demand.

The aim of the project is to show the possibilities of renewable hydrogen use in industry and in mobility through substitution of a part of the fossil hydrogen used in refinery in Schwechat, Vienna and by using it for the mobility sector. The mobility sector is emitting approximately 30% of the overall greenhouse gas emissions in Austria [48]. Thus, the reduction of imported fuel would bring significant environmental effects. However, the refuelling infrastructure is insufficient yet, and regulatory requirements for hydrogen refuelling stations (HRS) are challenging.

Within the project, further expansion of the HRS network will be facilitated and solutions for official calibration of gas quality and dispensed hydrogen mass will be developed. Demonstration of the developed concepts of green hydrogen production by electrolysis as well as the corresponding logistics for distribution will be carried out in the follow-up project UpHy II. Both projects will show different business cases for the production and use of green hydrogen in industry, thus, promoting further projects and reducing hydrogen production costs.

Similar projects are currently under development all over Europe [49], additionally, an important criterion for funding of these projects in Austria was the wide dissemination of results, organisation of excursions and involvement of all different stakeholders into the current developments in decarbonising activities. For that reason, the findings of such demonstration projects should be part of the university programs.

Measuring the Transition: Assessment Options for Ecological, Economic, and Social Impacts

As Sects. "Framework and Scenarios of Decarbonizing Energy Systems" and "Renewable Hydrogen as an Enabler for Deep Decarbonisation—Current Insights from Austria" already envisaged developing, scaling up and rolling out innovative technologies will play a significant role for the decarbonization of the energy sector. As there is no "silver bullet" available for decarbonization, a mix of measures and technologies has to be established [50] in order to achieve net-zero emissions in the European Union by 2050 [51].

The need for developing and implementing innovative technologies for decarbonization shows the increasing importance of engineering for achieving energy system transition and decarbonization goals. Accordingly, it becomes more and more obvious that sustainability concepts and how sustainability can be measured should be part of the education of future engineers. Integrating sustainability assessment methodologies into the curriculum of engineers helps to ensure the development of economic, environmental and societally advantageous technologies [52]. Viere et al. [53] also point out the necessity for integrating Life Cycle Assessment (LCA) into higher education against the background of the need to establish climate and environmentally friendly goods and services. Mälkki and Alanne [54] conclude that teaching LCA and integrating economic as well as social aspects should be part of energy-related programmes in higher education. Especially research-based teaching, where students learn how to conduct LCA studies on their own is recommended. From an educational point of view it can be recommended to strengthen a more holistic view on emerging technologies, where also qualitative systemic values are discussed. For quantifying the transition it is especially important to train future practitioners for a better understanding of the impacts of methodological choices.

Experience from environmental consulting firms reveal that the theory on LCA and sustainability assessment needs to be complemented with practical experience from real-life projects in order to avoid uncertainties of measuring sustainability which one has to deal with in practice. The following section on the one hand points out the uncertainties and on the other hand, discusses approaches how to overcome them.

Measuring sustainability and its uncertainty

Today several promising technologies at different Technology Readiness Levels (TRL) for accelerating decarbonization pathways exists. A challenge is to identify the most efficient technologies with the biggest potential. Accordingly, there is a strong need for decision support tools based on technology assessment in order to choose effective technologies for decarbonization. Such approaches should at least account for four dimensions: (i) decarbonization potential (e.g. CO_2 emissions), (ii) feasibility and scalability, (iii) cost and affordability, and (iv) potential accelerators and enablers [55]. Already in this simplified and generic recommendation on indicators for choosing technology options, two aspects become obvious:

1. The need for multi-dimensional assessment approaches accounting for environmental, economic and social impacts—decarbonization potential, cost, and affordability.
2. The need for combining quantitative and qualitative assessment approaches—cost, enablers and accelerators.

Greenhouse gas savings (GHG-savings) are an acknowledged indicator for technology and product assessment in a policy context—e.g. for biofuels and fuels of non-biological origin within the Renewable Energy Directive (RED 2018/2001/EC) or green hydrogen within the CertifHy approach. Whereas extending the assessment towards sustainability assessment is still not widely standardized although for certain sectors the development of standards has been started. For the bioenergy sector for example the ISO 13065:2015 "Sustainability criteria for bioenergy" defines sustainability criteria for the assessment of environmental, economic and social impacts of the bioenergy supply chain to achieve comparability without defining thresholds. As the defined sustainability criteria are narrowed down—e.g. only one indicator for the economic dimension "Produce and trade bioenergy in an economically and financially viable way"—this standard is not sufficient for a holistic sustainability analysis along the whole value chain. Campos-Guzman et al. [56] showed that most studies on assessing the impacts of renewable energy technologies focus just on a handful of criteria: climate change effect, soil use, technical aspects such as distances, nominal power, resource availability, capital costs and operation costs, social acceptance as well as employment creation [57]. Although these few criteria cover those identified as the most important by stakeholders [58], technology assessment has to go beyond these quantitative indicators, by also including qualitative indicators.

Especially when it comes to assessing the contribution of energy technology to reaching the SDGs, it needs more holistic approaches such as Life Cycle Sustainability Assessment (LCSA). Literature shows that LCSA is not yet a standardized approach although it is defined as a combination of LCA, Life Cycle Costing (LCC) and Social Life Cycle Assessment (SLCA) [59]. LCA as well as LCC are widely applied to energy technologies and numerously discussed in the literature [60–66] and there are also standards for conducting an SLCA [67]. Due to the degree of freedom each of these approaches reveals uncertainties in the methodological choices and assumptions of the practical implementation for measuring the decarbonization potentials.

Measuring Sustainability for emerging technologies

Assessing the environmental, economic and social impacts of emerging technologies provides some special challenges. On the one hand, measuring the impacts already at an early design stage is important as the degree of freedom concerning technological choices is high and the potential costs for implementing an adaption in the process are low [68–70]. On the other hand, there is a lack of data available for conducting the assessment [71]. Additionally, focusing the assessment on just a few indicators such as GHG-saving, economic indicators such as capital and operation costs, production costs, also may lead to misleading conclusions for emerging technologies as they do not provide the full picture. A renewable energy technology for example can be advantageous compared to a fossil technology in terms of GHG-savings and social aspects, but may show disadvantages concerning costs and land use. Accordingly a one-dimensiaonal assessment is not sufficient for decision making.

A vivid example is biobased chemicals. Biobased chemicals produced from lignocellulosic feedstock do not necessarily show a GHG-saving potential compared to those produced from 1st generation sugar and starch crops and also the CO_2—abatement costs are higher for 2nd generation products [72]. There is a strong emphasis on GHG abatement according to the EUs chemical strategy. It explicitly calls for “minimizing the environmental footprint of chemicals in particular on climate change” [73]. Nevertheless, it lacks the recognition of other sustainability aspects. In future assessment additional sustainability aspects should not be neglected. Especially qualitative sustainability aspects often lack recognition as technology assessment is mainly driven by quantitative assessment methodologies.

As already emphasized in Sect. “Renewable Hydrogen as an Enabler for Deep Decarbonisation—Current Insights from Austria”, green hydrogen is one of the major players in decarbonizing the energy system and industry. Power-to-Product technologies and underground methanation of hydrogen (H_2) and CO_2 in depleted gas reservoirs (geomethane) are other examples that show that a one-dimensional assessment approach may result in misleading conclusions. Green hydrogen shows significant GHG-savings compared to its fossil counterpart made by natural gas steam reforming [74]. But still, the production costs of green hydrogen, as well as geogenic methane, are higher today than H_2 and CH_4 from state-of-the-art technologies [75]. Examining the trajectories concerning cost development and options for energy system integration brings to light the future benefits of the Power-to-Product technology beyond today’s frameworks.

Accordingly, there is a strong need for the application of more holistic approaches. Qualitative indicator analysis could be such an approach to examine the cross-cutting issues related to the sustainability of emerging technologies.

Qualitative indicator analysis

Because of the existing challenges for sustainability assessment of emerging technologies a qualitative indicator analysis approach, specially designed for assessing

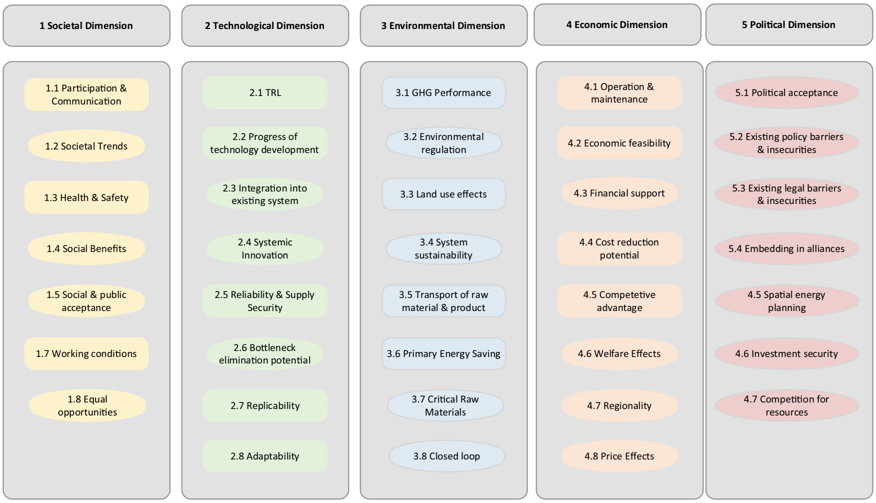

Fig. 22.3 Set of qualitative indicators for a multi-dimensional sustainability assessment of Power-to-Product Technology (*source* Friedl et al. [77])

Power-to-X system approaches [76], has been developed. Within indicator analysis, five dimensions are investigated: social, technological, environmental, economic, political. Each dimension contains a set of indicators and sub-indicators. Figure 22.3 shows the qualitative indicators for each dimension. In total there are 38 indicators, whereof 22 are related to the environment (elliptical box) and 16 are product-related (squares).

The indicators are assessed with two major approaches (i) literature research and (ii) expert interviews and knowledge. Additionally, the findings of LCA and techno-economic as well as macroeconomic analysis are taken up too. Finally, this gives the bigger picture of the impact of Power-to-Product technologies. From a practical point of view, the assessment of the qualitative indicators should start at the beginning of a Power-to-Product project and accompany it until its successful implementation.

Qualitative indicator expands the scope of technology assessment as it goes beyond the quantitative environmental and techno-economic assessment which tends to reduce the impact of a decarbonization technology to a single number. The quantitative indicators—e.g. GWP [kg CO_2eq/unit], production costs [€/unit], CAPEX [€], OPEX [€]—are not sufficient to make statements about the relevance of the technology to achieve an energy transition as monetary factors are usually not accounted for [78]. Assessing the qualitative indicators shown in Fig. 22.3 compensates for the loss of information and broadens the scope for decision-making.

Streamlined greenhouse gas assessment

In order to achieve comparability of product-related GHG-savings and secure accountability for policy goals, the calculation of GHG-savings is often streamlined. A prominent example is the RED approach (2018/2001 Annex V, C) [79], which is also taken up by CertifHy for calculating the savings for green hydrogen [80]. Compared to the ISO 14040/44 LCA approach [81, 82], the life cycle approach in these schemes is reduced to a single formula. The advantage of such a simplified approach is that better comparability of results is ensured even if different practitioners calculate the GHG-saving. This is mainly due to the limited degree of freedom concerning methodological choice: the RED (2018/2001) approach only allows physical by-product allocation based on the energy content. In contrast to that ISO14040/44 accepts different allocation approaches and moreover recommends applying system expansion [83]. It is possible to account for the use of the by-product which results in an environmental credit due to the avoidance of primary production.

The effects of allocation vs. avoided burden approach can be significant. Lantz et al. [84] report for ethanol from straw a GHG emissions of 11 $gCO_2eq/MJEtOH$ calculated with RED methodology and −12 $gCO_2eq/MJEtOH$ choosing an ISO14040/44 conform avoided burden approach. This is only one example for the effect of methodological choices on the overall LCA results. However, the handling of multifunctionality and its impacts on the overall LCA result and conclusion are lively discussed in the literature, see e.g. [85–87].

Table 22.2 shows the mass and energy allocation factors for ethanol, lignin and sludge. Depending on the approach 22% up to 38% of the environmental burden is attributed to ethanol.

The situation gets more complex if an avoided burden approach should be applied as (i) the practitioner must have more information on the by-products and (ii) some choices have to be made based on the product information. It is crucial to know the by-products specification as well as the potential utilization strategies. In the case of using sludge from ethanol fermentation as fertilizer, the nutrient composition must be known (see Table 22.3).

For lignin two possible utilization strategies should be shown here with high practical potential. Lignin can be used for thermal energy production substituting thermal energy from lignite or it substitute bitumen as a binder in asphalt. Table 22.4 displays both aspects.

Accordingly, the total potential GHG-credits in the case of EtOH range from approx. 171 $gCO_2eq/MJEtOH$ and 29 $gCO_2eq/MJEtOH$. Although the calculations

Table 22.2 Defining allocation factors for 2nd generation EtOH production (Fazeni-Fraisl [88])

	Mass allocation	Energy allocation
	[t/t_{EtOH}]	[MJ/MJ_{EtOH}]
Bioethanol	1	1
Lignin μ prod	1.96	1.41
Sludge μ prod	1.54	0.21
Allocation factor EtOH	22%	38%
Allocation factor lignin	44%	54%
Allocation factor sludge	34%	8%

Table 22.3 Defining the GHG-credit for using sludge as fertilizer (Fazeni-Fraisl [88])

Emission factors	Value	Unit
N-fertilizer[a]	0.22	kg $CO_{2eq}/kg_{fertilizer}$
P-fertilizer[a]	2.03	kg $CO_{2eq}/kg_{fertilizer}$
K-fertilizer[a]	0.63	kg $CO_{2eq}/kg_{fertilizer}$
CO_{2eq} credit nitrogen (N)	129.18	kg/t_{EtOH}
CO_{2eq} credit potassium (K)	9.24	kg/t_{EtOH}
CO_{2eq} credit phosphorus (P)	0.03	kg/t_{EtOH}
SUM CO_2eq credit for fertilizer substitution	138.46	kg/t_{EtOH}
SUM CO_2eq credit for fertilizer substitution	5.14	g/MJ_{EtOH}

[a] Emission factors are obtained by GaBI ts 10 LCA software

Table 22.4 Possibilities for choosing a credit approach for lignin (Fazeni-Fraisl [88])

Parameter	Value	Unit
lignin LHV	19.49	MJ/kg
Lignin μ prod	1.96	t/t_{EtOH}
lignin energy	38,200	MJ/t_{EOH}
emission factor thermal energy from lignite[a]	117	$gCO_2eq/MJ_{lignite}$
emission factor bitumen[a]	329	$gCO_2eq/kg_{bitumen}$
CO_2eq credit for lignin substituting lignite	4,469,447	gCO_2eq/t_{EtOH}
CO_2eq credit for lignin substituting lignite	166	gCO_2eq/MJ_{EtOH}
CO_2eq credit for lignin substituting bitumen in asphalt	645	gCO_2eq/t_{EtOH}
CO_2eq credit for lignin substituting bitumen in asphalt	24	gCO_2eq/MJ_{EtOH}

[a] Emission factors are obtained by GaBI ts 10 LCA software

shown here represent a simplified approach, it becomes obvious how methodological choices influence the overall result for the GHG-savings of a product. Such methodological choices hamper the comparability of different studies and lead to uncertainties when it comes to decision-making. On the one hand, showing the effects of different by-product utilization pathways supports decision making to find out a favourable by-product utilization pathway from an environmental point of view. On the other hand, one has to know about all the assumptions leading to a specific result to make valid statements on the GHG-savings of a product. For measuring the transition, streamlined approaches such as the RED (2018/2011) formula provide sound results based on physical relationships.

From Scientific Research to Realisation and Implementation in Education

Climate change has been a well-explored field of research since the late nineteenth century. Svante Arrhenius was the first scientist who made a quantitative link between changing CO_2 concentration and climate in 1896 [89]. Nevertheless, modelling climate change began with Charles David Keeling, who started in the 1960s to measure the global accumulation of CO_2 in the atmosphere which is up to date the most important environmental data set [90]. Processes and technological developments to mitigating climate change have been the main focus of the Intergovernmental Panel on Climate Change, established in the late 1980s [91].

Sustainability, sustainable development, concepts for mitigating climate change, decarbonization and energy transition are research topics that gained significantly more and more importance in recent years [92, 93]. From 2015 to 2019 nearly 1,200 scientific papers were published where the topic of energy issues in context with climate change mitigation is focused [94].

This development in research is crucial because climate change is more than just an environmental challenge, it is part of the relationship between and the interdependence of the environment and human survival [95]. Hence, the environmental problems must be communicated and explained to the public, in order to increase awareness of people at any age and profession. Decisions are always made by people with their individual worldviews and values. Human activities has been the dominant cause for climate change and the avoidance of a dramatic climate change requires sustained substantial reductions of emissions and actions for decarbonzation [96], like described at Sect." Framework and Scenarios of Decarbonizing Energy Systems". Accordingly, education is, therefore, a key tool to increase the public knowledge of environmental challenges and initiated the above-mentioned transition to a decarbonized energy sector [97, 98]. The higher education sector is beginning to recognize this unprecedented challenge. This is of central importance, hence these institutions are in the unique position for teaching and preparing the leaders of the future society [91]. The impetus and opportunities of colleges and universities are substantial, perhaps not reachable by any other organization [99].

Although, the best way is to extend environmental education not only in the curriculum of higher education institutions, also in primary and secondary schools [97, 100]. Environmental education for children should be designed as a meaningful and pleasing learning experience because such an experience will influence the lifelong attitudes, values as well as patterns of behavior regarding the natural environment [101].

There is a consensus among pedagogic staff that environmental education is still lacking emphasis in the curriculum of schools worldwide. The main reasons are: (i) difficulties to integrate, because of the interdisciplinarity of environmental education, (ii) insufficient linkage between social and natural science, and (iii) a lack of professional development for the teachers to acquire sufficient knowledge about environmental education [101].

A further problem is that the development of ecological ethics in colleges and universities is often insufficient or missing. Many higher education institutions have a one-sided view of environmental education. Although courses have been set up there, the formulaic teaching often cannot increase the environmental awareness of the students. On the other hand, a lack of systematic and comprehensive ecological knowledge, increasingly weak ecological perspectives, as well as deficits of ecological behaviour, can lead to a lack of socio-ecological awareness and understanding by students [102].

However, there are also promising showcases for ecological ethics of education institutions, like the concept of "Green University"—a model of environmental excellence and for sustainable development initiated by universities [103]. To name some examples for that: the "campus environmental project" was developed by the United States California university, the "green university plan" by the University of Washington and the "campus green action" by the Canada University of Waterloo [103].

For sustainable development, it is the turn of the UN member states to implement the Agenda 2030. In Austria for example, the Uninetz project [104] was launched to address this issue. In this project scientists and artists from 18 universities have joined forces to present options for implementing the UN Sustainable Development Goals to the government. The involvement of students in this project made an interweaving of the disciplines of science and education possible.

The members of SDG 4 identified several issues and tasks to transform the education system [105]. The six most relevant examples are: (i) concepts of education for sustainable development in the training and further education of educators; (ii) educational concepts for sustainability in all curricula at universities and colleges; (iii) development and implementation of sustainability strategies in a participatory manner at all universities; (iv) promotion, support and increased visibility of adult education in the context of sustainability, (v) projects and a compulsory subject with the focus on sustainability in schools; and (vi) need for interdisciplinary education. Furthermore, the experts working at SDG 7, dealing with measurements for the transformation of the energy sector, see enhancing education as a necessary step for decarbonization [106].

Concluding from that, a holistic approach for environmental education and sustainable development is needed. Innovative concepts for teaching are crucial to make a change and raise students' environmental awareness. The curriculum of the study and programs have to be adapted according to that, since education reforms are curriculum-based [107]. The implementation of international summer schools is an opportunity for curricular reform and internationalization. Especially the connection of summer schools with science seems to be a perfect fit since results from research and development (R&D) are the central basis to demonstrate new approaches and provide up-to-date knowledge. An example for such summer school developed by a research institution is the summer school "ASSET2022" offered by Energy Institute at the Johannes Kepler University Linz in Austria. There international students have the opportunity to learn from ongoing research projects about renewable energy, energy efficiency and concepts for decarbonization of the economic system.

Conclusion

Decarbonization of the energy sector requires a holistic system analytic approach. Research and development continuously create new solutions to deal with environmental issues. Sector-specific clusters of action cross-sectoral requirements for climate-neutral energy sources are essential to decarbonize the energy and economic system. The energy-intensive sectors, e.g. cement, steel and chemical industry, must rapidly switch to climate-neutral energy sources. Although transformation in the industry sector is not enough to reach climate neutrality and for sustainable development, the other sectors (mobility, households, etc.) have to be addressed too. With the substitution of fossil fuels by renewable energy, the topic of energy storage is becoming more and more important. In this context, green hydrogen is one possibility to enhance decarbonization. The hydrogen demands constantly increased over time and by looking at the research landscape and forecasts, it can be assumed that the importance of hydrogen will continue to increase significantly. In general, the scaling up and rolling out innovative technologies are of central importance for the decarbonization. R&D is active in developing new, innovative technologies, which are needed for sustainable development. A challenge is to filter high-potential technologies according to their environmental, economic and social impact. Various methods exist to evaluate new technologies, but mostly only a handful of criteria are addressed for assessing the sustainability impacts. There is a need for a more holistic approach in technology assessment, which must be used in science and also taught and implemented in the education system.

The necessary steps and pathways for decarbonization of the energy sector exist and research institutions and companies are already implementing them. Research, the search for new knowledge using scientific methods and in a planned manner with the purpose to gain new knowledge and innovation, is by its nature always a step ahead to teaching. The transfer of scientific insights to the public and the interlinkage to education has to be enhanced to prepare future engineers for sustainable energy production. This is an issue, which has to be solved, because education is essential for successful decarbonization. Research and teaching must go hand in hand. A promising way for that is to adapt the curricula of the educational institutions. Therefore, innovative concepts for teaching are crucial to make a change and raise environmental awareness among students. The implementation of international summer schools is a promising example to make an interlinkage between research and teaching.

In conclusion, a holistic approach is needed for decarbonizing the energy sector. The development and implementation of new technologies are not enough a transition in the education system is necessary. Therefore research and education must be linked. When the rigid curriculum is made flexible the transfer of knowledge from research to education is possible.

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Chapter 23
Nature-Based Solutions for Water Pollution Control: Promoting Environmental Education Through Case Studies

Alexandros I. Stefanakis

Abstract As we are increasingly becoming aware of the complex global environmental issues and their impact on our societies and everyday life, we realize that the traditional problem-solving approach cannot provide effective solutions anymore. The transition to a circular economy where resources efficiency, waste minimization, and zero emission are the target requires new tools and a new approach. Nature-based solutions (NBS) are concepts inspired by nature that can provide such alternative solutions along with ecosystem services, improved well-being and resiliency. However, the capacities and the educational potential of NBS remains largely unexplored and such innovative programmes and resources around NBS are currently missing from formal and informal education programmes both for professional engineers and practitioners as well as students and academics. This chapter proposes that this gap can be closed through the implementation of NBS case studies in collaboration with educational institutions that can widen the audience that can access and learn from such initiatives. For this, different NBS demonstration projects are presented from around the world related to wastewater management and reuse.

Keywords Nature-based solutions · Constructed wetlands · Wastewater management · Reuse · Engineering · Problem solving · Circular economy

Nature-Based Solutions and the Circular Approach

In the time of climate change or climate crisis, we see a planetary change progressing faster and faster and its impact at local, regional and global scale. It is well argued that the extent of this impact to the ecosystems and the human society will soon become irreversible [1]. The search for sustainable solutions and alternatives to deal with these pressing issues, however, is not new and is still ongoing. A first milestone was the Agenda 2030 for Sustainable Development that defined 17 Sustainable Development

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Goals (SDGs), analysed into 169 targets, with the key goal being "transform our world" [2]. The Paris Agreement in 2015 set the global target to reduce the greenhouse gas emissions and promote a carbon–neutral growth in the near future [3]. This climate crisis today shapes the form of an emergency as it is expressed across the biosphere; the water cycle, either regional or global, is changing, exposing different regions of the world to extreme events (floods, droughts, erosion). The destruction of mangroves, forests and other habitats, as well as the biodiversity loss are also expressions of this climatic emergency in the natural environment.

We believe that the main reason that led to this current situation can be found in the linear economic model on which the economic and societal progress was based on over the last century [4, 5]. The rapid economic growth and the global reduction of poverty over the last decades [6] was achieved through the linear management of resources such as energy, food and water that caused environmental issues such as resources depletion, ecosystem degradation, biodiversity loss, environmental pollution, etc. The new proposed economic model of a circular economy aims exactly at changing this paradigm by minimizing and even eliminating the use of natural resources and the production of waste and emissions [7–9]. In this model, the use of the finite resources is optimized to reach the maximum efficiency, the recovery of materials and products at the end of their useful life becomes the centre of a new design approach and the use of renewable energy replaces the consumption of the finite and polluting fossil fuels [4, 10].

Circular economy emerges as a useful and necessary approach that will push forward the transition to a sustainable society and tackle climate change–related risks [7, 11]. Decoupling economic growth from resources use through resource dematerialization lies in the core of circular economy [12]. However, the current status of the circular transition reveals that the global society has still a lot to do; the circularity index of the global economy dropped from 9.1% in 2018 to just 8.6% in 2020 [13]. This means the challenge today is to go beyond the basic scope of carbon removal and storage and support actions such as the restoration of natural land and water ecosystems, and change the design approach of new infrastructure especially in the urban environment [14]. Such a new infrastructure concept is achieved with green infrastructure or nature-based solutions (NBS).

The Need for Nature-Based Solutions

The concept of NBS is receiving nowadays increasing attention due to its enormous potential to address many environmental and social challenges such as climate change mitigation, water and wastewater management, zero carbon emissions, participatory planning and governance [12, 14, 15]. NBS can provide multiple ecosystem services to further boost resilience [16] and limit the impact of climate change on human and natural ecosystems [12]. NBS can contribute to the decarbonization of the economies by neutralizing emissions of businesses and enterprises, promoting this way the sustainable management of resources.

The concept of NBS derives from the dual need to preserve and protect the natural environment while developing engineering technical solutions that aim at controlling nature [17]. NBS go beyond the traditional engineering approach that only gives the perception of control, and are based on a new integrated approach that considers the environment (wildlife habitat, cities) and the technology working together to benefit nature through closing as many as possible cycles. In other words, NBS are inspired and supported by nature and encompass the ecosystems and the ecological functions in land use planning and ecological engineering design [18–20]. The approach of NBS implementation is always developing and progressing to further integrate the societal aspects, the ecological principles, processes and organisms with the established engineering practice into a new holistic approach for problem solving [21].

Education for Nature-Based Solutions and Nature-Based Solutions in Education

Though the idea of integrating engineering and ecology in NBS has been discussed for many decades, it is only these last years that their potential has been realized. The lack of a wide awareness on NBS capacities is not only seen in developing countries as one would expect, but also in developed ones. Especially in the field of water resources management, authorities and the wide audience are still not aware at a great extent of the NBS potential to provide cost-effective, resource oriented and sustainable alternatives [22, 23], and benefits equivalent or even higher than conventional grey infrastructure [24, 25]. Thus, a crucial factor for an optimum and wider promotion of NBS in different economic and social contexts is a proper and holistic education. This should come in two levels:

(a) NBS education for engineers: as the role of engineers in problem solving is fundamental, the transfer of NBS knowledge to engineers is respectively important. Engineers should be further educated on the planning and development of alternative challenging solutions using NBS in order to provide upgraded and environmentally friendly solutions that optimally utilize the available investment capital. A continuous education and provision of up-to-date information to engineers will also contribute to avoid repeating past solutions that were not financially or technically effective. For example, in the field of wastewater management the use of grey infrastructure such as mechanical and conventional grey technologies in remote and rural areas (i.e., in a decentralized manner) and/or in low-income regions has often been a failure rather than a success [23, 26, 27]. This is why NBS such as Constructed Wetlands have been suggested for decentralized wastewater management [23, 28]. A new generation of engineers should possess competencies not only related to water quality and process design, but also to legislation, circular economy, climate, and construction materials [25].

(b) NBS in education: so far, the established approach consists in the integration of NBS and ecological engineering within a well-established engineering degree (e.g., environmental or civil or chemical engineering). However, even this approach is not always applied in the engineering discipline, while often the content of courses does not provide the contemporary NBS concepts rather an obsolete approach of past decades. Moreover, even in non-engineering curriculums there is a lack of needed courses on natural and social sciences [29, 30], which is also depicted in the limited research on the social aspects of NBS and circular economy [7, 23].

NBS have a unique value to contribute to and cover several societal needs to reach a sustainable development. Existing knowledge and experiences of NBS applications indicate their potential to overcome the limitations or gaps of conventional engineering solutions. For example, NBS can further provide an environmental character in engineering/infrastructure interventions by conventional engineering that minimize the environmental impact but do not offer respective environmental benefits [17]. This is emphatically illustrated through real-scale NBS applications that integrate the core of NBS principles, i.e., multidisciplinary approach, multifunctionality, systems thinking, ecosystem services design, besides the common measurable targets set by traditional engineering such as treatment efficiency [14, 17, 21]. The following sections provide in brief such examples of NBS applications from around the world where educational and training activities were also part of the project development.

NBS Case Studies

Greywater Treatment and Reuse from a University Dormitory in a Constructed Wetland

A full-scale constructed wetland (CW) system was built and monitored under the local arid and warm climate at the Neyshabor University campus in Iran (approximately 1250 m above sea level) for demonstration and educational purposes [31]. Neyshabor University is a public Institution with several faculties and many dormitories. For this project, one dormitory was selected with approx. 200 students. The recorded average water consumption was 20 m^3/day, which corresponds to an approximate consumption of 133 L/PE/day (population equivalent). At Neyshabor University, wastewater management has been problematic, which puts more pressure on the Neyshabor Drinking Water Treatment Plant (DWTP) that is located near the University. Before this project, the dormitory wastewater was collected in simple underground septic tanks that create a risk for the contamination of groundwater resources that are used as water supply at the DWTP. Moreover, the region is suffering from water scarcity, while water consumption is still increasing. Therefore, the University authorities had to find a way to address these issues effectively. The goal was to provide an option for sustainable wastewater management including the reuse of the

Fig. 23.1 The demonstration constructed wetland system at the Neyshabor University in Iran for dormitory wastewater treatment

treated wastewater for irrigation within the University campus to reduce the freshwater consumption and the associated costs. Considering the above, the Neyshabor University decided to implement a demonstration project using a NBS that would not only solve the issue of wastewater management but would also allow for the involvement of students. Such a project could further become part of the educational process by familiarizing the students with NBS through site visits and by training students in sample taking and carrying out physicochemical analyses in water samples. This facility will also be used as a showcase to highlight the feasibility of implementing NBS in the region.

The demonstration facility was built in 2018 and comprises a primary stage (anaerobic baffled reactor; ABR), a secondary stage (vertical flow constructed wetland; VFCW) and a third polishing stage (horizontal subsurface flow constructed wetland; HFCW) (Fig. 23.1).

The ABR (47.5 m^2) is made of concrete, has a holding capacity of 108 m^3 and is divided into three chambers (50:25:25% volume per chamber) [31]. The last chamber is equipped with a submersible pump (10 m^3/h) that transfers the ABR effluent to the second stage VFCW bed.

The VFCW has a surface area of 200 m^2 (unit area demand 1 m^2/pe; [32]). The VFCW has a bottom drainage layer (30 cm) made of cobbles (20–63 mm), a coarse gravel layer of 20 cm (5–15 mm) and a top fine gravel layer of 60 cm (2–5 mm), while a 20 cm freeboard is also considered. Furthermore, the VFCW surface is divided into two cells (left and right) to allow for the alternate feeding and resting periods, following the typical operation mode of VFCW systems [32]. The VFCW is fed intermittently and is planted with giant reed (*Arundo donax*) and pampas grass (*Cortaderia selloana*) in the bed perimeter, both local plant species [33]. The water level is maintained 20 cm below the fine gravel layer surface, thus making this system partially saturated. This setup allows gravity flow to the third stage and promotes an anaerobic environment at the VFCW bottom, necessary for various pollutant removal processes. This design also maintains the water in contact with the plant roots during the University summer break (July - August), when there is a minimum wastewater flow.

The HFCW bed has a surface of 250 m^2 (unit area demand of 1.25 m^2/pe) and a hydraulic residence time (HRT) of 4 days, a minimum required value reported for effective performance [34]. It contains a 1-m gravel layer (8–20 mm) with a freeboard of 20 cm and the water level is maintained 5 cm below the gravel surface, while it is planted with local common reeds (*Phragmites australis*). Both wetland beds have an estimated porosity of 30%, a 45° band slope and are lined with a compacted layer of fine sand and clay and an impermeable HDPE membrane (1.5 mm) protected via a geotextile sheet. The final treated wastewater (HFCW effluent) is collected with gravity in an underground tank (160 m^3 capacity), where it is pumped out for reuse, i.e., landscape irrigation within the university campus and irrigation of non-bearing trees [31].

Since its operation start, this NBS proved to be successful in providing a treated effluent complying with the national standard for reuse. The overall removal efficiency for various pollutants was 88.9% (BOD_5), 86.0% (COD), 92.2% (TSS), 63.5% (PO_4-P), 66.5% (NH_4-N), and 65.7% (NO_3-N) [31], performing better than other similar systems found in the literature [35, 36]. Total coliforms were also removed (99.9% or 2.43 log units) and the effluent value was below the national limit, as it is also reported in general for hybrid CWs [37].

This CW system demonstrates that NBS can be effectively applied in full-scale for sustainable wastewater management in an arid and warm climate region. It also showed that it can be easily built, since more than 90% of all materials and equipment needed can be sourced locally within the country. This is a particular advantage for low income regions with limited resources. Furthermore, it is now operated by the non-specialized University staff, while educational activities are already carried out by the academic staff at the facilities, e.g., the ecological technology of CW is already taught and frequent site visits take place. In addition, there are plenty site visits by representatives of the local water authorities, industries and enterprises who want to learn more about this sustainable technology.

Demonstration Constructed Wetland for Municipal Wastewater Treatment in Oman

A full-scale CW facility was built in Oman for demonstration purposes aiming at treating municipal wastewater to provide a treated effluent appropriate for irrigation [38]. This project implementation and monitoring is the PhD topic of a student by the Sultan Qaboos University and was also funded by Haya Water (Oman Wastewater Service Company) and The Research Council Fund.

The research facility was built at the conventional wastewater treatment plant (WWTP) of Quriyat city (45,000 residents) that treats 300 m^3/d of wastewater under a desert environment. The tested CW is a modified French system, i.e., it has two stages of VFCW beds with modified substrate media composition and 100% effluent recirculation [38]. The wetland area is 995 m^2 (Fig. 23.2). The first stage (VF1) consisted of three beds of 123 m^2 area each and the second stage (VF2) of two beds, each of 312.5 m^2. An anoxic tank (AT) with a submersible mixer allowed for up to 100% recirculation of the treated effluent (TE). The inflow was 50 m^3/d, i.e., 25 m^3/d of raw wastewater and 25 m^3/d of recirculated effluent (100% recirculation), with a hydraulic loading rate (HLR) of 0.135 m/d and an average influent organic load of 66.9 g COD/m^2/day [38]. The substrate media in the VF1 beds was a 35 cm-thick washed sand layer on top of a 20 cm-thick fine gravel layer. The same media were used in the VF2 beds with respective thicknesses of 65 and 20 cm. Both CW stages were lined with a HDPE membrane (1.5 mm), and planted with native common reeds (*Phragmites australis*). The goal was to reach the effluent national irrigation Standard A [39], enabling the effluent reuse in agriculture, an increasingly in-demand objective in hyper-arid environments [40].

During the first operational phase the system operated with 100% effluent recirculation, while during the second phase several operational modifications were tested focusing on enhancing the denitrification process, and thus total nitrogen removal. These modifications were: (M1) longer HRT in the AT to enhance the growth of denitrifying bacteria, (M2) longer HRT in the VF2 beds by stopping the recirculation and increasing the water level in the VF2 beds to 30 cm below the media surface, (M3) removing the spray nozzles in the VF2 beds to reduce the oxygen supply and establish

Fig. 23.2 Aerial picture of the full-scale research VFCW facility at the conventional wastewater treatment plant in Quriyat, Oman

anaerobic conditions in the wetland body, and (M4) step-feeding of raw wastewater to the second stage pump station and its alternative by providing an external carbon source [38].

During the first operational phase, the two-stage VFCW reached high removal rates for most pollutants, i.e., 98.7% (COD), 97.8% (BOD_5), 98.6% (TKN), 99.5% (NH_4-N), and 91.2% (TP), while no pathogens were detected after the final chlorination step [38]. However, the tested CW could not meet the limit values for NO_3-N and TN. It is known that the VFCW design has a high nitrification capacity [32, 41], especially under warm climates [23], which was confirmed by the low TKN and NH_4-N effluent values (1.23 and 0.28 mg/L, respectively). It was shown that the first VFCW stage could already achieve full nitrification (average NH_4-N effluent 0.5 mg/L) but also provided a high nitrate in the VF1 effluent (average 76.5 mg/L NO_3-N), reaching an average NO_3-N and TN of 23.46 mg/L and 24.97 mg/L, respectively, in the treated effluent (VF2). Apparently, effluent recirculation enhanced TKN and NH_4-N removal compared to the conventional French CW, considering the lower reported removals for TKN in other studies (84%; [42], 85%; [43], 93%; [44], 90%; [45]). Despite the positive effect of effluent recirculation through inflow dilution and carbon addition for denitrification, the increasing nitrate load resulted in an increased effluent nitrate concentration. Thus, additional modifications were tested to improve nitrate removal and help reaching the effluent Standard A.

The various modifications tested aimed at providing and enhancing the conditions necessary for denitrification, i.e., anaerobic environment and sufficient carbon source. It was found that a longer HRT in the anoxic tank, the increased water level, and the removal of the spray nozzles in the VF2 beds had only minor impact on nitrate reduction. However, step-feeding of raw wastewater, a modification previously tested in CWs [46], into the second stage or dosing by an artificial carbon source provided an effluent quality that complied with the strict nitrate limit value (11 mg/L).

This research facility is a perfect example of the actions needed to promote and demonstrate the potential of NBS through research and development. As the topic of a PhD thesis, the full-scale CW served the research goal to provide an optimized design. As a demonstration facility, this CW confirmed the high performance and ecological character of CW. The local authorities, i.e., Haya Water (Oman Wastewater Service Company) were not only convinced to invest in this solution but are already planning to increase the use of CW technology in many areas in Oman and respective tenders have been released. This facility is also used as a demonstration system for many companies and engineers that have the chance to learn about this NBS, while regular site visits are arranged by many Omani Universities.

Full-Scale Aerated Experimental Constructed Wetland for Municipal Wastewater Treatment in the UK

One of the first aerated CW in the UK was installed and tested at the WWTP of Petersfield, Hampshire, a rural town with 20,000 inhabitants, with the support of the University of Portsmouth [47]. The WWTP receives 4750± 1080 m^3/d and consists of preliminary treatment (screening and grit removal), iron salt addition (FeSO4) for phosphorus (P) precipitation, primary treatment (two sedimentation tanks of diameter 15 m each; PST), secondary treatment (10 trickling filters of diameter 24 m each; TF) and two secondary sedimentation tanks (SST) of diameter 23 m each. There is no disinfection step before the final discharge to the adjacent River Rother.

An experimental aerated VFCW was built in 2013 (Fig. 23.3) and receives a quarter of the inflow (i.e., 1250 m^3/d) at a HLR of 1.08 m/d. This VFCW was a testing and demonstration facility of a new wetland design, that of the aerated CW. It was installed to provide effluent polishing, i.e., it received the SST effluent. The VFCW is a saturated aerated downflow wetland (1160 m^2), filled with a 70-cm medium gravel layer (8–15 mm) [47]. The aeration lines are placed on the bottom and artificial aeration is continuously provided using a mechanical air compressor (5.5 kW) at an average air flow of 300 m^3/day. The treated wastewater flows by gravity to the final discharge point. The VFCW is lined with HDPE membrane (1.5 mm) and planted with cattails (*Typha latifolia*).

The aerated VFCW provided a high removal efficiency and managed to significantly improve the effluent quality of the WWTP that fulfilled the legal criteria for environmental discharge and reuse without a disinfection step. Organic matter (BOD_5 and COD; 99.5% and 97.7%, respectively) and ammonia (99.5%) were completely removed in the system, with the VFCW accounting for most of the NH_4-N removal [47]. The AVFCW alone showed 76% removal of BOD_5, 22% of COD and 89% of NH_4-N, demonstrating that artificial aeration creates the necessary aerobic conditions for enhanced nitrification and organic matter oxidation [32, 48, 49]. The VFCW improved the WWTP efficiency for all the usual physicochemical parameters using a much smaller footprint (3–6 times) compared to passive CWs, while it also provided performance stability. The tested treatment train was found capable of providing a final effluent quality complying with the limits of the Urban Wastewater Treatment

Fig. 23.3 Pictures of the research aerated VFCW system at Petersfield WWTP in the UK

Directive [50], which has been adopted in the UK [51], allowing for the final discharge to surface waters, and with the WHO limits for unrestricted irrigation [52]. It is worth mentioning that the secondary effluent (without the wetland) did not meet the respective European standard for Total Nitrogen, neither the WHO limit for *Escherichia coli*. This study on the first aerated VFCW further provided insight on the fate of bacteriophages in CW systems and their role in the removal of pathogenic bacteria by revealing strong correlations between bacteriophages and bacterial indicators.

This research facility proved at the full-scale the potential of advanced CW designs to deliver a high effluent quality. As many academic institutions were involved in the design and monitoring of this system, it was and still is used in the educational process in many Universities through regular site visits and analysis of its performance. Moreover, as one of the first aerated CW systems, it also demonstrated to the technical community that NBS have still the potential to adapt and be optimized to fit the required scope and provide customized solutions by integrating established light engineering techniques.

A Demonstration Ecohaus at the German University of Technology in Oman

A unique demonstration project was implemented by the German University of Technology in Oman co-funded by The Research Council. The project called 'EcoHaus' was the construction of the university's guesthouse; a two-storey building (250 m^2) with net-zero-energy performance (Fig. 23.4) [23, 53]. The goal was to develop and test a prototype sustainable, energy-efficient building that would serve not just as an example of a green building but would also provide thorough education for the next generation of architects and engineers to be able to develop a sustainable building culture. What is of particular interest is that the university decided to not out-source the planning and supervision works of this project, but instead to build up competence in sustainable design and construction methods in-house; thus, a team of

Fig. 23.4 View of the demonstration EcoHaus building (left) and the adjacent constructed wetland (right) at the German University of Technology in Oman

faculty and graduates was formed, so that a new generation of competent architects and engineers would benefit from this project [53].

The development of the project involved workshops organization for students on energy-efficient designs and construction methods. Various studies were carried out for the construction system and materials choice by the team. As a result, a high thermal resistance was achieved using a cavity wall, for which a light-weight pumice-and concrete block on the exterior layer, a loose-fill insulation of perlite in the center layer, and a heavy compressed earth block for thermal mass on the interior layer were used [53]. Another study showed that energy consumption was mainly regulated by the dehumidification of the very humid outside air during the summer period; thus, the air-exchange was minimized by only providing the hygienically necessary air-exchange and switching from a convective to a radiant cooling system. An initial simulation revealed that during summer, when active cooling is imperative, the EcoHaus uses 30% less cooling energy than a building constructed based on the local municipality regulations, and 60% less cooling energy compared to a building with simple construction methods that are used in most projects. A further students study monitored the visual comfort in the house as well as measured the indoor air-quality, indicating the optimum orientation to minimize the heat gains from the East and West sides through fully opaque facades as well as shading the South windows with external shades. Also, to minimize noise pollution from the central technical room, better door insulation and less noisy pumps were installed for the cooling system. The energy needs were covered by photovoltaic panels installed at the roof of the building [53].

Furthermore, in order to render the EcoHaus completely sustainable, a NBS was selected to provide onsite wastewater treatment from the building. The constructed wetland (CW) was designed to receive all wastewater (black and grey) by gravity and to provide a cost-effective and sustainable treatment allowing for the treated effluent reuse in garden or green roof irrigating [23]. The CW flow rate of the CW is 1 m^3/day, equivalent to 5 persons [54]. Wastewater flows into a covered settling tank (5 m^2) for primary treatment, i.e., solids settling and flotation of fats and oils. The septic tank effluent overflows to a HFCW (15 m^2). The water level in the HFCW is regulated approx. 5 cm below the gravel surface to prevent odors and mosquitos. Today, the wetland is planted with common reeds (*Phragmites australis*), while an irrigation field is also created for the irrigation of local trees and shrubs with the treated effluent [23].

This demonstration EcoHaus integrated with a NBS wetland system at the University campus in an arid and hot climate is an independent structure in terms of energy and water demand, with minimum energy consumption and maintenance requirements. It demonstrates in an excellent way of how green building practices and NBS can be combined to form green and sustainable solutions for new building structures with onsite wastewater management and reuse.

Conclusions

As climate change is progressing, we are coming across major global and regional environmental impact to the ecosystems and the human society. We gradually realize that only with sustainable solutions and alternatives we can address these challenges. The relatively new proposed model of circular economy has the potential to alter the patterns and inherent flaws of our economic growth by optimizing the use of natural resources, minimizing the production of waste and promote sustainable practices such as the recovery of materials and resources efficiency. This transition to a circular economy needs to be supported by the appropriate tools that will change not only the materials use but also the design of solutions. In this aspect, the concept of nature-based solutions changes the way we implement engineering projects by integrating already in the design principles such as climate change mitigation, zero carbon emissions, resiliency, ecosystem services and societal aspects into a new holistic approach for problem solving.

In this ambitious new approach, education has a crucial role to play to address the current status of NBS, e.g., the lack of awareness regarding their potential in both developed and developing regions. A further dissemination of NBS will come through transfer of NBS knowledge to engineers to avoid repeating ineffective past solutions and through integration of NBS and ecological engineering courses in academic curricula. An efficient day to do so is through the upscaling of NBS and implementation of NBS projects outside the lab in real operating conditions. Demonstration NBS projects that are accessible to professionals, engineers, authorities, academics and students are the important to promote the awareness around NBS concepts and educate the present and future generation of engineers and planners. Having these in mind, this chapter presented case studies of NBS applied in the field of wastewater management in different climatic, economic and social contexts, where full-scale NBS projects were used to demonstrate the capacities, benefits and the integrated sustainable approach of these systems and to showcase how such systems can be part of wider academic and educational activities by connecting the contemporary research with NBS examples.

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Chapter 24
Environmental Education and Location-Based Technologies for Investigating Urban Threats and Promoting Nature-Based Solutions

Francesca Ugolini and David Pearlmutter

Abstract Protecting the natural environment for future generations is a central concern of modern humanity. European policy acknowledges how important it is for younger citizens to have sufficient knowledge about global issues, and the competences required to act on this knowledge, in order for society to achieve sustainable solutions to its development challenges. However, recent evaluations report under-achievement and declining interest among students in science-related subjects, which represent the basic knowledge for future job careers. Attracting students to Science, Technology, Engineering and Mathematics (STEM) and raising their awareness on environmental protection are two of the main challenges for growing a better future society. Interactive, location-based digital technologies can be of great value to involve students actively in these subjects, and to connect the virtual world to real life. In this chapter we describe a series of learning methodologies that have been applied in three European educational projects funded by the European Union in the recent past, promoting the development and the use of Location Based Games (games for mobile devices) to make STEM subjects and environmental education more attractive and multidisciplinary. These projects demonstrate how environmental education, when conducted in an immersive and interactive way, can inspire students to understand the ecological challenges we face and creatively address them through nature-based solutions.

Keywords Environmental education · Location-based games · Digital technologies · Urban sustainability · Nature-based solutions

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Introduction

The Changing Landscape of Environmental Education

Among all the challenges facing humanity in the twenty-first century, perhaps none is considered more urgent than protecting the natural environment for future generations [1]. Therefore, environmental education, through both formal and informal channels, has a critical role to play in raising the awareness of youth to environmental threats and building the capabilities needed for addressing them. In Europe, many schools already strive to inculcate a sense of responsibility among their students toward environmental stewardship, encouraging them to cherish, value and protect the natural heritage of the earth and contribute to its preservation. Acquiring knowledge about environmental assets, and helping to enhance them by volunteering in the local community, are two of the most fundamental ways in which young people can start to make a positive impact [2, 3].

At the same time, pursuing effective environmental education through conventional teaching models is strikingly insufficient. The first reason for this is that the meaning of environmental "literacy" has changed drastically, and will continue to do so [4, 5]. Digital technologies and new pathways for the communication of information provide the essential tools for younger generations to be effective in their environmental learning and action. With each passing year, society becomes more deeply connected with electronic media and portable devices, and environmental education must embrace the potential of these constantly evolving technologies to positively affect the way that all of us, young and old, comprehend the space around us [6, 7]. A remarkable range of applications is continuously being developed, including location-based support tools for learning in nature (e.g. My Tracks, PeakFinder Earth, Pl@ntNet) and didactic tools (http://www.educationalappstore.com) that can transform the ordinary learning experience and attract more and more users to emerging environmental knowledge.

The second reason is that the educational experience must be relevant. This means reversing the trend by which conventional classroom teaching has caused many students to become disengaged from environmental topics in the fields of Science, Technology, Engineering and Math (STEM). Today's students are the workforce of tomorrow, and the jobs that will be available to them when they graduate will require a higher understanding of technology, a greater confidence in problem-solving, and more collaboration with professionals around the world.

STEM education in fact plays a critical role in preparing students for future careers as adults, as nearly 80% of these careers will require some STEM skills. A stimulating STEM education is essential for developing the basic analytical, problem–solving and critical thinking skills, central to school achievement and workforce readiness in the twenty-first century [8]. Engaging students with experimenting and checking assumptions against data makes each of them a better problem-solver, and encourages creative thinking as preparation for a complex and changing world.

However, the Organisation for Economic Co-operation and Development (OECD) assessment programme PISA [9, 10] revealed serious issues of under-achievement in STEM among 15-year-old students, especially in the Southern and Eastern European countries. Many researchers have concluded that students' low or declining interest in STEM subjects is partly due to the teaching methods applied, which often form a collection of detached, de-contextualised and value-free facts, not connected to the students' own experiences. In such context, raising curiosity and connecting school subjects to the student's own interests and experience may increase the perceived relevance of the subject. Therefore, connecting scientific theory with real-life problems is essential to capture these students' imagination, and this often requires schools to be equipped with labs and other facilities as well as highly qualified and effective teachers - and in some cases, a connection to outside experts from private enterprise and institutions of higher education.

Creative thinking and communication also require "soft" skills, which implies the integration of Art with the overall vision of a STEM education (i.e. "STEAM"). One of the most powerful ways to do so is by cultivating the student's digital skills through the creation of "serious games", which require the development of creative storytelling, drawings and storyboard development, along with creative game mechanics in the form of software development and programming [11–13].

European Priorities and Strategies for the New Environmental Education

Many of the strategic priorities recently established by the European Union (EU) and its institutions envision a future for Europe which is more sustainable, healthier, and digitally advanced. Therefore, programs and policies promoted by the EU focus on fostering social goals that combine these environmental and technological aspects [14].

The urgency of climate change mitigation is a prominent priority within the EU agenda, and it has been included as a main pillar of the Next Generation EU—the Recovery Plan for Europe which aims to facilitate a robust economic recovery for the European countries. This includes the establishment of environmental priorities such as climate neutrality by 2050, and enriching biodiversity according to the goals of the United Nations (UN) Agenda 2030 [15]. Central to the EU's environmental agenda are the objectives of the European Green Deal, which incorporates economic innovation, growth and social needs in its vision for sustainable development [16].

European policy acknowledges how important it is for new generations of citizens to have the knowledge about global issues, and the competences required to act on this knowledge, that are needed for society to achieve sustainable solutions to its development challenges. It is seen as crucial to provide openly available educational materials relating to the causes and effects of climate change, loss of biodiversity, and other relevant environmental issues—but also guidance on working toward transformative solutions, whether it be for implementing broad goals such as a circular economy and green economic growth, or more specific strategies like agroecology in agriculture [17].

A promising sign can be seen in the increasing awareness by the younger generations of global challenges, as demonstrated for instance by the "Fridays for Future" initiative. As interdisciplinary responses to global challenges have a strong motivational value, connecting STEAM education to such environmental, economic and social activism can increase students' interest and enjoyment when learning science and other school subjects [18]. Education should thus be expanded to put a spotlight on international issues such as environmental degradation, sustainability, climate change, recycling, and water security, and emphasize the goals of the UN's 2030 Agenda for Sustainable Development [15].

Europe's future environmental vision places a high priority on the advancement of digital technologies and related skills and competences, through the Digital Education Action Plan [19]. Recently issued by the European Commission, this plan clearly states that it is imperative to raise the quality and inclusiveness of education and training systems and improve the provision of digital skills. In order to prevent the widening of "digital divides" across Europe, a coordinated transformation must be carefully planned and managed in which educational systems in different countries are able to adapt to the new circumstances of the information age.

In 2021, the European Court of Auditor [20] estimated that some 35% of adults in EU member states do not have sufficient digital skills, and more than 75 million people have no digital skills at all. In addition, in 2018 the OECD [21] found that less than 40% of European educators felt confident to use digital technologies in teaching, although there were divergences between EU Member States, and more than one third of 13–14 year old students did not possess the most basic proficiency level in digital skills. The situation may have changed during the COVID-19 pandemic during 2020, when distancing rules and restrictive isolation measurements set by the governments worldwide obliged educational organizations to use digital communication technologies for distance learning over prolonged periods. Even "digital natives", albeit proficient in the informal use of hi-tech tools and social media, do not necessarily learn to make systematic use of Information and Communications Technology (ICT) in an academic setting.

At the same time, the pandemic has evidenced how the reliance on digital tools for distance learning can have a negative impact on many aspects of the school environment. In its current stage of development, distance learning with ICT has been assessed by many students as boring, stressful and ineffective [22], and they miss the physical presence at school for its social aspects and face-to-face contact. Therefore, an important challenge of digital skills—which are so fundamental to all economic sectors—is that they should not be in conflict with the quality and interest in learning. It is now time to bridge the technological gaps in education systems, and close the "learning divides" to facilitate equitable and inclusive access to education—and it is also important to guarantee that students take an active role in their own learning process, allowing them the kind of quality interaction and confrontation that is needed for fostering effective teaching.

A central aim, therefore, is to transform the use of digital tools from “passive” media such as digital sources of content to “active” tools such as e-learning platforms, or platforms for digital game development, which can be integrated with other methods that make learning more effective and interactive—like hands-on, inquiry-based approaches and debating. This will also allow the involvement of students with different interests and skills to use innovative tools and assess their own performance.

One of the most exciting of these active approaches using digital technology is “Location-Based Games” (LBG). An LBG is an interactive game designed to be played on a digital device in motion, with a strict connection to the physical geographic location of the player. LBGs are well-suited both to convey educational knowledge and to encourage physical activity. Due to the “fuzzy border” between the game and the real world, players can develop a closer connection between virtual and real environments—which in turn engenders stronger emotions than conventional educational games.

LBGs profit from the fact that mobile devices like smartphones and tablets are so ubiquitous, using these technologies to integrate the players’ geographical position directly into the game.

In fact, LBGs can be played within a city or at a remote location in nature, maintaining connection through GPS without the need for an internet connection—still an important consideration in areas with limited coverage. LBGs allow augmentation of the physical reality, with its environmental elements represented in real-time and in semantic context, in order to exchange information about the surroundings with digital interaction. Gaming and coding are both important educational themes that come into play, since the students have the opportunity to learn and improve programming skills through the game development. In addition, since they are intimately tied to the physical landscape, these “serious games” have the potential to become a significant tool for achieving educational goals related to sustainable environmental development [23, 24].

Urban Threats and Nature-Based Solutions

As the majority of the planet’s human population now lives in cities, the challenges posed by urbanization continue to multiply. Among these urban threats, some of the most pressing relate to climate—not only global but also local climate change. The urban heat island effect is now pronounced in many cities, meaning that increasingly frequent heat waves are even more hazardous within cities, especially for vulnerable urban population groups [25, 26]. Much of the overheating caused by urbanization is related to a lack of vegetation and the predominance of dry, heat absorbing surfaces, which contributes to diminished biodiversity in the built-up area as well as a lack of filtration for pollutants that end up in the air and soil, and particularly in bodies of water—both on the surface and underground [27].

In fact, one of the less publicized effects of urbanization is that the paving of the city's terrain has affected the flow of its rivers, by diverting their pathway, channeling them into concrete canals, and sometimes culverting them in tunnels below the cityscape. Thus, many cities in Europe have "hidden" rivers which once flowed freely on the surface, but are now entirely underneath the urban fabric. While these underground rivers are still part of the city's natural drainage system, their flow is constricted to the extent that they multiply the risks of flood damage. For instance, the city of Florence (Italy) has some 30 covered rivers that could pose serious flooding hazards, especially considering the increasing frequency of extreme weather events and the area's geomorphological conformation [28, 29]. If, over time, urban development has led to a river's envelopment and an increase of risk, new concerns such as climate change will amplify these risks in the future. It will therefore be important to give nature back its spaces, and by so doing make cities more resilient.

In recent years, the restoration of water flows in urban areas and the rehabilitation of aquatic life to a largely 'natural' state is of increasing interest—but further promotion and awareness, especially in the younger generations, is needed. The process by which covered rivers are re-exposed to the environment is known as deculverting, or 'daylighting'. Daylighting rivers can create new habitat for plants and animals, potentially reduce flood risks, and create new 'green corridors' through urban areas—which in turn provide the additional benefit of recreational services. This type of strategy is a prominent example of addressing urban threats through *Nature-Based Solutions* (NBS).

NBS have been identified as effective ways to address both environmental and societal challenges that are exacerbated by global climate change. They were originally proposed as a new category of solutions for not only mitigating climate change, but also adapting to its effects, while at the same time protecting biodiversity and improving the economic livelihood of local populations in a sustainable way. NBS have recently come to be seen in a more general context, and within EU policy frameworks are considered to be an innovative means for creating jobs and sustainable growth as part of a green economy [30].

Objectives of the Chapter

The involvement of younger generations in facing the environmental challenges of our time is crucial. Just as clear is the reality that environmental education, while essential for giving youngsters an understanding of the relevant environmental phenomena, must engage students in a more active, participatory way. We propose in this chapter that digital, location-based tools are a key for making this conceptual transition, and that these tools can be used by educators not only to provide examples of existing solutions but to impart the skills that are needed to find further solutions.

Fig. 24.1 Environmental education activity using location-based digital technologies

To illustrate this approach, we present an overview of several recently completed projects in which we have integrated location-based technologies in environmental education (Fig. 24.1), with an emphasis on investigating urban threats and creatively confronting them with NBS.

Case-Study Initiatives

Overview of the Three Projects

Since 2012 we have participated in a series of three European projects involving students in secondary education (middle and high school). The common aim of these projects is to foster students' knowledge and awareness regarding environmental protection, and to promote the application of an integrated STE(A)M approach which is centered on the use of digital technologies. The main motivation behind this approach is to make STEM more attractive for students, and to involve them in a holistic learning experience.

The first two of these projects, INVOLEN *Intergenerational Learning for Nature Conservation Volunteers* (2012–2015) and RAISE *Raising Environmental Awareness in Young People*, (2015–2017) applied this approach for intergenerational learning in natural protected areas of the Natura 2000 Networks, while the third project, DAYLIGHTING RIVERS *Science Education for Civic Ecology* (2017–2020) focused specifically on the environmental threats faced by rivers in urban areas, in the context of human activities and urban planning (see Table 24.1).

All of these projects incorporated digital applications on mobile devices, particularly LBG, allowing students to collect and manipulate georeferenced information as a vehicle for stimulating their self-involvement in the educational activity, and in general as a way of transferring the "environmental message" to a wider young audience.

Table 24.1 Overview of the case study projects, detailing the period of implementation, participating countries and program framework

Project name	Dates of implementation	Participating countries	Funding framework
INVOLEN (Intergenerational Learning for Nature Conservation Volunteers)	2012–2015	Italy, Greece, France, Hungary, Slovenia	Lifelong Learning Programme (GRUNDTVIG Multilateral Projects)
RAISE (Raising Environmental Awareness in Young People)	2015–2017	Turkey, Greece, Italy	Erasmus + Programme
DAYLIGHTING RIVERS (Science Education for Civic Ecology)	2017–2020	Italy, Greece, Spain, UK	Erasmus + Programme

In the following discussion, we use these three projects as case studies to describe a number of innovative learning methodologies which have been developed and implemented. In addition, we describe the objectives of the projects, and the educational achievements realized. To illustrate intergenerational learning for nature protection we present the INVOLEN project in detail followed by a brief description of RAISE, and to illustrate science education for civic ecology we present DAYLIGHTING RIVERS project.

INVOLEN and RAISE: Intergenerational Learning for Nature Protection

INVOLEN targeted groups of youth together with groups of elderly residents in five European countries (see Table 24.1), all of whom had a shared motivation and passion for nature. The educational pillars of the project were "nature conservation volunteering", "digital technologies" and "intergenerational exchange"—and these concepts were combined within a non-formal as well as formal educational context (Fig. 24.2). The project aimed firstly to raise the interest of students toward nature and environmental volunteering, and to empower them with both the "green knowledge" and digital skills necessary for action. Secondly, by tapping into the experience and knowledge of elders, the project sought to raise the awareness of all participants to

Fig. 24.2 Intergenerational learning about nature protection using outdoor learning with digital location-based technologies and hands-on activities

the idea of "active ageing". Finally, the outputs of the project were meant to provide new creative tools for visitors to discover natural protected areas. In this way, the aim was not only to enhance the value of STEAM learning within the conventional school curriculum, but also to leverage the value of interaction with nature as a form of non-formal education.

In practice, each group of students was guided by a diverse team of facilitators, which included teachers, staff members of natural parks or other similar organizations, elders from the community, and one or more experts in ICT and digital gaming. Each of these interdisciplinary and generation-spanning teams collaborated for a total of about 30 h, in the process achieving and imparting a variety of different competencies.

Learning and Teaching Methodologies

Group work, brainstorming and "knowing by doing" were the primary means for each team to carry out its collaborative hands-on project, following a learning path that consisted of six "work units", as follows:

1. Identification of the areas in which competence was needed. Through interviews and questionnaires, the needs of the groups were identified in terms of the knowledge needed regarding the various nature conservation issues, volunteering, and the use of technologies, specifically Location-Based Games.
2. Introduction to Location-Based Games, what they are, and how they work, with examples provided by an ICT expert.
3. Collection of first-hand stories, legends and information about the natural area from elders, in informal meetings, interviews and field trips. These stories were used for the creation of the LBG.
4. Selection of the stories and information collected for the creation of the storyboard, which combined the historical, scientific information into a creative game scenario for the development of the LBG.
5. Visit to the protected area for volunteering activities, and for compiling pictures useful to the construction of a LBG. Practical experience and "learning by going" allowed the group members to achieve new knowledge and skills.
6. Development of the LBG, based on the storyboard, using a selected open source platform. This was the most challenging phase, as although many youngsters are familiar with mobile devices and social tools, this is less so with actual programming—while many elders are unfamiliar with these technologies and hesitant to engage with them. Therefore, differentiating the roles of youngsters and elders according to the phases of the game development allowed the team to leverage the skills of each age group, and to make the whole learning process more enjoyable.

This methodology was firstly piloted in the countries participating in the project, and then promoted widely through an international competition in which school groups across Europe could develop and submit an original LBG. This competition drew wide interest, with a total of 22 games submitted. In this way, no less than 335 participants were directly involved in the implementation of the INVOLEN methodology, including 189 youth, 88 elders and 58 facilitators. In addition, hundreds more were involved indirectly by participating in the "playtesting" of the games and by providing support to the various teams through interviews, information sharing, technical input and publicity.

The LGB that were submitted to the competition were first evaluated by an independent jury in each of the five countries represented, according to a common set of criteria. In each country one first-place winner was declared, and the five winning teams were invited to a final conference to present the work they had created and to compete for the overall European championship award. This conference took place in Florence, Italy in September 2015, and the competition presentations in particular represented the culmination of the INVOLEN project.

Part of the rationale underlying the international competition was to demonstrate that the methodology developed in INVOLEN could be applied in a range of settings, whereby relatively autonomous intergenerational groups could carry out the creative educational process with less direct support than was provided in the initial pilot testing. Each of these outside groups leveraged the expertise of local facilitators, as well as an online support center through which the project partners responded to over 100 queries during the period of the competition [31].

Evaluation of the Educational Achievements

The INVOLEN methodology successfully transferred knowledge, competencies and skills from one generation to another. At the same time, new friendships and a closer intergenerational link was created within the groups.

The local elders had the opportunity to tell their personal stories connected to the protected areas (describing their experiences there from when they were young, as well as their current contribution as volunteers). They transferred their knowledge on the local habitats and species, described the skills they had cultivated (e.g. in photography, storytelling) to the younger generation, and conveyed the importance of appropriate attitudes with respect to, and for, nature. They learned how to interact and communicate with the students, and were introduced to the novelty of how to make and play a mobile game. On the other hand, students could convey their knowledge and skills on the use of mobile devices, computers and digital apps to the elders and reinforce the dialogue and interaction between generations. The evaluation of the learning achievements in the piloting groups, which was conducted through a questionnaire survey among participants, highlighted the following points:

- Through increased awareness about environmental issues, participants developed more of a desire to solve such issues, and this gave many of them a feeling of being useful to society.
- There was an overall appreciation of the intergenerational exchange in both age groups, and a sense that the process did in fact enhance the quality of communications between them.
- New knowledge of educational gaming was acquired by young and old alike, and the students succeeded in developing and refining a range of IT skills.

The evaluation of intra-group cooperation, as perceived by the youth, the elders, and the group facilitators, was very positive overall. The results of this evaluation showed that the younger and older participants initially needed some time to “break the ice” before establishing free-flowing communication and mutual trust, and that the field visits and joint conservation activities helped greatly to establish bonding between the generations [31].

The success of the INVOLEN project led to a follow-up phase, known as the RAISE project, which was piloted in Turkey, Italy and in Greece with different classes of students. In this case, the INVOLEN methodology was applied as a form of “best practice”, fostering Learning Outside the Classroom, with successful results. Also in this project, participants recognized the benefits of intergenerational knowledge exchange between youngsters and elders, confirming the importance of the educational pillars of the projects. Among the achievements, both projects contributed to the following:

- Increased awareness about environmental issues and a desire to help solve such issues; a feeling of being useful to society; an eagerness to demonstrate to others the problems and solutions that relate to environmental conservation;
- New knowledge of educational gaming and the development of IT skills;
- Skills for observation and photography, classification of species and behaviors;
- Skills for hands-on activities and designing an experimental plan, data acquisition and analysis;
- Drawing and storytelling skills for the game scenario and storyboard;
- Technological skills for image processing and producing LBGs;
- Soft skills like group work, communication between peers and experts, and the ability to adapt one's own ideas to those of the others and find a common agreement or solution.

In addition, it was seen that in the context of the school classroom, the traditional teaching of subjects like science, technology, art and math, when combined with hands-on activities like experiments and experiential learning in nature, was an effective method of conveying not only knowledge, skills and competencies—but also of emotions.

Interest and motivation were definitely high during the course of each project, even when interest in the technical aspects (i.e. related to the digital game platform) was lacking. In fact, motivation and interest regarding LBGs were expressed mainly in the preliminary phases, when the students had to create the game storyboard and scenario, and in the play-test phase when they could check the final result. The intergenerational groups did indeed enjoy the collaboration among participants, most notably during the practical activities and field trips.

At the same time, it was clear that technical problems can interfere with the overall success of the experience. The use of digital apps specifically developed for one operating system (i.e. iOS or Android, but not both) tends to prevent some students from working on or playing the games on their own, or to showing the final game to relatives and friends. Creating and playing the LBGs was particularly appreciated, though, by those students who were especially skilled in ICT.

With regard to the practical aspects of the implementation, small-sized groups (of about eight students and two facilitators, including input from nature conservation experts in the appropriate sessions), was confirmed as optimal. This is very difficult in a school context, where the best solution is to split the students into thematic groups. A regular schedule of meetings every 7–10 days proved to be the best option, in order to maintain the engagement level of participants and to provide a steady learning pace and exchange of information between the different groups. Several of the participants expressed the wish to continue being involved in the project.

Most of the participants were also keen to make efforts and take action for environmental protection, showing frustration and disappointment about irresponsible human behaviour and taking personal initiative to clean up trails and ditches during the field trips.

DAYLIGHTING RIVERS: Science Education for Civic Ecology

As mentioned above, urban sprawl has led many rivers to be diverted or culverted below ground, to make way for the construction of new buildings, neighbourhoods and infrastructures. Burying these once free-flowing rivers has resulted in an increased risk of flooding, the loss of biodiversity along the stream, unmitigated water pollution and the disappearance of recreational and other services for the community that rely on the accessible flowing water.

Therefore, the restoration of exposed waterways in urban areas has gained increasing interest. The process by which the culverted rivers are uncovered and re-exposed to the environment is known as deculverting, or ‘daylighting’. As described above, such daylighting can stimulate the creation of ‘green corridors’ through the city, in turn supporting riparian ecosystems that are rich in flora and fauna, and at the same time offering benefits for the human residents of the city—ranging from flood protection to green riverside parklands.

The concept of ‘Daylighting’ rivers can also take on a further meaning, by shedding light on the issue of urban rivers—and in particular ‘daylighting’ youth consciousness, to raise awareness among the younger generation and inspire local action for global sustainability in water use.

This dual significance of ‘daylighting’ provided motivation for an innovative educational project funded by the Erasmus + Programme, known as DAYLIGHTING RIVERS. The project engaged students in secondary schools from European cities in interdisciplinary scientific investigations, not only in the realm of STEM but also in fields such as history, agriculture and economy—with a common focus on urban land cover and river studies, and with a further emphasis on the effects of urban sprawl on soil degradation and on river management.

DAYLIGHTING RIVERS aimed to reach several specific objectives:

1. Acquisition of knowledge and competencies related to the effects of urbanization on river quality and management;
2. Raising students’ interest toward STEM, working in a real and familiar context (“their river”) and including human studies, history, art and design (STEAM); and
3. Raising students’ digital technology skills through the use of LBG.

Learning and Teaching Methodologies

The methodology developed in DAYLIGHTING RIVERS included two integrated levels of knowledge and competence acquisition. The students were engaged in general environmental themes (e.g. river management, urbanization effects, hydrological risks etc.) and also performed one or more Learning Units on specific issues, for a better understanding of that particular topic. Each Learning Unit closely followed the structured Pedaste’s model [32] of Inquiry Based Learning (IBL).

In general, DAYLIGHTING RIVERS adopted a cyclical work flow process consisting of four steps, each branching off into separate Learning Units, as summarized below.

(1) The module starts with a brief *introduction* of the project and on a chosen environmental theme connected to the local area (either urban or rural) by using multimedia material or brainstorming among students, to raise curiosity and lead them into the investigation. Indeed, the broad theme may be investigated under different aspects, addressed by specific Learning Units.

(2) Students and teachers *implement one or more Learning Units,* covering STEAM subjects through the use of multidisciplinary materials, and following Pedaste's model of IBL [32]—which represents a scientific investigation method structured in five steps (orientation, conceptualization, investigation, conclusion and discussion/communication). Descriptions of the Learning Units can be found by accessing the project website at https://www.daylightingrivers.com/. The activities of the Learning Units can be carried out by the students in different ways:

   – Students may work individually or in groups (different groups may run the same activity, or different activities);
   – Activities can be carried out during classes on one or more school subjects;
   – Activities can include a range of learning experiences, including field research exercises, scientific laboratory experiments, and modeling with digital technologies.
   – Students may use accessible low-cost materials or more specialized scientific equipment, depending on the availability and the choice of the Learning Unit.

(3) Students summarize the main findings from their investigations and draft conclusions which will be useful for the production of the outcomes, such as *reports on existing site problems, design projects for daylighting rivers,* and the production LBG. These outcomes will require the application of specific tools, software and new technologies, as appropriate to represent the acquired knowledge.

(4) P*resentation of outcomes* to the public (including stakeholders such as experts, local administrators, parents and the general public) as an important opportunity for students to reflect on their experiences and find the most appropriate communication tools and methods.

DAYLIGHTING RIVERS has involved hundreds of students in Italy, Spain and Greece in investigations that involved a variety of STEAM subjects, as they investigated hidden rivers in their towns, the river ecosystem biodiversity and human threats such as water pollution, and the history and social and economic impacts of river management (Fig. 24.3).

Again, as in the previous projects, students were challenged to create a LBG to spark their creativity and engage peers in knowing more about the issues that they investigated. An international competition was launched to promote LBGs as a way

Fig. 24.3 Inquiry based learning and location-based game development are combined for understanding the problems of urban rivers and seeking nature-based solutions

to foster digital skills and for raising environmental awareness on the river issues in local contexts. A total of 16 teams from different European countries registered for the competition, and six of them submitted the final materials—despite the hardship of the COVID-19 pandemic, which constrained schools to distance learning.

The competing project entries, each of which included a Summary Report and Location Based Game, demonstrated an impressive level of scientific knowledge gained by the students, and also highlighted two different styles of presentation. On one hand, the students presented the content in their Summary Report using rigorous scientific language, and on the other hand they succeeded in translating this content into a creative fantasy story as the basis for the LBG to be played on the mobile device.

Evaluation of the Educational Achievements

As part of the overall DAYLIGHTING RIVERS project, an evaluation process was conducted after the pilot implementation of the educational modules. This evaluation aimed at identifying the students' perceptions, and more specifically how their attitudes had changed, regarding STEM learning—and how this might affect their self-efficacy in future career decision-making. To gain insight into these issues, questionnaires were circulated to students at seven of the participating schools in Italy, Greece, and Spain (as well as Turkey, which participated in the pilot stage). The main findings of the survey showed that the implementation of even one educational module led students to perceive slightly positive changes in their attitudes towards STEM subjects, and that these students also perceived slightly higher levels of career decision self-efficacy. These general findings are encouraging when considering the implementation of further educational modules with additional groups of students, and could provide valuable insight for those who address environmental challenges in the teaching and learning process.

The survey results also offered a “snapshot” of the knowledge, interests and attitudes of the students in those schools which pilot-tested the Inquiry Based Learning methodology and helped the project team to adapt this IBL methodology to the needs of the students so that they could further develop their multi-disciplinary STEAM knowledge and all-round environmental awareness. In this spirit, several important conclusions may be drawn:

- The awareness among students regarding their local rivers is rather low, whether it is larger or smaller rivers that cross the cities and towns in which their schools are located.
- The students reported higher levels of knowledge regarding general topics like river ecology and pollution, but less regarding the effects of climate change and the history of local rivers. Many did express interest in learning more about these topics, demonstrating that an initial introduction to an issue tends to generate further interest to learn about it.
- Such interest can be generated towards issues that students previously did not know a lot about, but are at the centre of public discourse, such as the effects of climate change. This implies the need to promote systematic knowledge of environmental issues at school, and projects such as DAYLIGHTING RIVERS project can encourage and systematize such learning.
- As might be expected, students tended to be less knowledgeable about covered rivers that are hidden from view, than open rivers which are visible. While covered rivers are rarely included in science teaching materials, and usually are not high in the local agenda, they embody a range of environmental issues which together offer a great STEM learning opportunity. The single “story” of a hidden river can cultivate critical thinking through inquiry-based and interdisciplinary learning, and can introduce students to realms that are not typically found in the school curriculum, such as urban planning.
- Most of the students expressed confidence in performing the type of active tasks that are emphasized in IBL, such as fieldwork, working with a project team, and communicating with others, both verbally and in writing—and they showed interest in learning more about these activities.
- Students also expressed a generally high degree of confidence in using digital tools, to the extent that they were familiar with them. Not surprisingly, they were less confident with specialized software such as GIS, LBG development platforms and satellite interpretation tools, with which they were less familiar.
- As might be expected, there was significant variation among students regarding their prior knowledge and skills with digital technology. In each country, there was a group of more technically-oriented students (22 in Italy, 15 in Greece, 13 in Spain and 50 in Turkey) who felt confident using more sophisticated digital tools. Such students can play a key role in this type of project, since by assigning them a more active role in the technical tasks, they can assist both their teachers and fellow classmates and thus provide an advantage for the whole class.

- It was reassuring to find that students generally have a positive attitude toward environmental protection and do feel the need for active civic engagement, demonstrating a high level of environmental awareness. There were, however, variations between different schools in this regard. In Italy and Spain, for example, environmental attitudes among students were seen to be more positive than in Greece and Turkey.
- There were significant minorities (30–40%) of students in some schools who stated contrary beliefs, for instance that "people worry too much about the environment" or that "it is not their business to be concerned about threats to the environment". It is clear, then, that schools have both an opportunity and a responsibility to instill in their students a critical thought process which could lead to more positive environmental values.
- Such a task is especially challenging, considering the many contradictory influences that students may have outside the school framework. For this reason it is so crucial to revitalize STEM learning, and to convey reliable scientific knowledge on environmental issues. As illustrated here, this can be done by employing IBL and involving students actively in hands-on work—and leveraging multiple school subjects to explain environmental threats in an interdisciplinary way.
- Results of the survey revealed that the majority of students have a positive attitude toward science and technology subjects. At the same time, nearly half of all students (in total, and within single countries) consider these scientific subjects to be difficult. The Daylighting Rivers concept addresses this head-on, by integrating methods that are engaging for the students, promote cooperation, and employ digital tools that capture their imagination. This approach is meant precisely to make difficult material more accessible, and encourage more students to develop an active interest in science.

The findings described here should be understood within the context of the specific countries and schools that were surveyed. The students' knowledge, perceptions and interests are undoubtedly influenced by the particular school's organization and activities (especially its science curriculum), and the local conditions and communal norms regarding environmental issues in general, and river management and planning in particular. At the same time, we believe that the insights offered here can provide valuable guidance to environmental educators—so that they may better identify their students' needs, and find opportunities to help them develop well-informed, independent values and opinions of their own.

Conclusions

In this projects, we have demonstrated how the thoughtful use of location-based technologies can enhance environmental education, not only by actively immersing students in the science that underlies environmental threats, but also showing them the possibility of addressing them in new and creative ways—with nature-based solutions.

What all of these educational projects offer is the chance for people to engage with nature in a meaningful way, from a young age when their perceptions and values are in a highly formative stage. This engagement is far from one-dimensional; it ranges from inquiring about environmental problems to creating interactive games to promote nature-based solutions. It extends the classroom to the larger world, and encourages students to actively promote these solutions by volunteering in their community. As suggested by Guiney [33], nature volunteers feel an intimate connection to nature—and this is a connection that began in childhood. If this is the case, we have a good feeling that the methodologies illustrated here might seed such a connection in a youngster's mind, or awaken one that was already there. Protecting nature starts with learning about the problems, but requires this sense of attachment from anyone who hopes to actually solve them.

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