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Co-creation as a driver of geo-environmental learning approach to adapt cities to climate changes

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Article

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Abstract

Climate change is humanity's 21st century biggest challenge. Due to the higher rates of soil sealing, its effects and consequences are expected to be more severe in cities. To mitigate climate change effects or adapt cities to them, several approaches can be adopted, namely by adopting nature-based solutions, such as blue and green infrastructures. During the course of Study and Behaviour of Soils, of the undergraduate degree in Sustainable City Management, taught at the Institute of Engineering of the Polytechnic Institute of Coimbra (ISEC-IPC), students are faced with the need to present solutions to solve an urban problem by implementing a green solution. Students are involved in a co-creation process to carry out this academic activity. This project-based learning methodology is seen as an active learning process, and its three stages are fully described in this paper. Students' perceptions, academic results and assiduity are compared and contrasted to enhance the benefits of such an approach in geotechnical education. Results show that not only are students more willing to participate in class, reducing absenteeism, but students' final project results increased when compared with a more traditional pedagogical approach. Also, based on the survey, it is possible to conclude that the co-creation approach allows the development of transversal skills and competencies, and such a learning process should be implemented more often during the undergraduate degree.

1. Introduction

Since the founding of the first university in Europe, teaching approaches have been mainly based on lecturing (Brockliss, 1996). The traditional lecture-based classes or courses, usually defined as passive learning, are centred on the teacher, who decides what matters to be learnt (Michael, 2006) and does not allow the development of students' thinking. (Fidalgo-Blanco et al., 2017). Current practice and state-of-the-art suggest that applying new methodologies, based on "ask more, instead of telling" methods, leads to a growth in students' performance (Henderson et al., 2011). In STEM (science, technology, engineering, and mathematics), undergraduate courses average failure rates in conventional lecture courses are 1.5 times higher than in courses where teachers adopt active learning solutions (Freeman et al., 2014). Freeman et al. (2014) also conclude that there is an increase in percentile, passing from 50th in traditional lecture-based lessons to 68th when active learning methodologies are implemented. Contrary to passive learning methodologies, student-centred learning approaches consider the student's position and will, conditioning the pace of learning and what is learnt (Michael, 2006). Despite the current knowledge of pedagogical methodologies, several factors may explain the resistance to change, namely faculty's past experiences as students (Bovill et al., 2016) or habit toward an existing practice, namely by colleagues (Sheth & Stellner, 1979). Also, the perceived risks associated with applying pioneering learning approaches might be an obstacle to switching educational models (Sheth & Stellner, 1979).

Based on the previous statements, adopting teaching methodologies that lead to better involvement of students in the learning process is essential, focusing on problem-solving rather than memorisation (Michael, 2006). Michael (2006) states this will lead to more long-lasting and meaningful learning. By definition, active learning is a process where students are forced to reflect upon ideas and how to use them in practice (Collins III & O'Brien, 2003). During the active learning methodology, students are invited to self- and peer-evaluate, assessing skills while they collect information and solve problems.

Numerous authors have already described several examples of student-centred learning approaches. Among

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the methodologies Michael & Modell (2003) summarised, one may find problem-based or case-based learning and cooperative/collaborative learning/group work. Co-creation methodologies overlap with active learning (Bovill, 2020), as they enhance the interaction between students and teachers and between students and students. According to Michael (2006) and Freeman et al. (2014), students adopt a more active role, performing different activities for gathering information, solving problems, and reflecting upon the current state of the art. Co-creation also enhances students' satisfaction and performance, bringing competitive advantages to educational institutions (Hofstatter, 2010) as they are more engaged with and in the subject (Araújo et al., 2021).

According to Bovill (2020), several types of co-creation can be identified: i) students co-researching university-wide projects; ii) students collaborating with staff in research and scholarship projects; iii) students representatives working together with staff on committees; iv) students participating in course design review committees, being involved in redefining courses and their curricula; v) students as consultants, assessing teachers and providing teaching feedback; vi) students proposing their final projects of masters' thesis topic. Students already do some of the tasks mentioned above at the Polytechnic Institute of Coimbra (IPC), as in other higher education institutions in Portugal. For example, student representatives in the Pedagogical Commission work with faculty to improve courses and their curricula, and part of the teacher's yearly evaluation depends on the students' perception. However, these activities result more from legal or statutory frameworks than co-creation processes. In addition, co-creation initiatives are not often implemented at individual and classroom scales.

To boost the implementation of co-creation processes both in the classroom and across the various modules of the courses, IPC has been promoting, since 2021, pedagogical training courses entitled "Learning based on co-creation processes". This method agrees with what Michael (2006) states concerning teachers becoming learners to reach the projected outcomes when newer methodologies are implemented. Through this experience, teachers can create an environment that encourages active learning. Today, some promising results are visible in the Sustainable City Management bachelor, whose pilot experience is presented in this study.

As part of the evaluation methodology, in the Soil and Behaviour of Soils course, students are invited to propose geo-environmental solutions (nature-based solutions) to mitigate adverse impacts related to climate change events, described as urban challenges, such as urban rapid flood or urban heat island effect. Their proposals are the result of continuous work throughout the semester. However, class assiduity and academic results have decreased in recent years. Aiming for higher involvement of students and better academic results, since the academic year 2022/2023, cocreation methodology has been implemented as the primary pedagogical approach during the development of students' green infrastructure projects. The present study describes all the details of the implemented pedagogical process, giving particular emphasis to the proposed tasks. With these tasks, students are expected to develop a comprehensive understanding of the chosen urban challenges and implement critical and collaborative thinking tools, hopefully leading students to innovative solutions.

To evaluate the results of this new pedagogical approach, two ways frameworks are used: i) an online survey carried out on the last day of classes to understand students' perception; ii) data comparison of academic results and class assiduity achieved in the 2022/2023 academic year and previous academic years. These preliminary results support the urgent need to switch pedagogical approaches in teaching subjects related to geotechnics.

2. Geotechnics' contribution to the sustainable management of cities

2.1 Sustainable cities

In 2015, a historic agreement reached by almost 200 world leaders formalised the recognition of climate change as a global emergency. The "Paris Agreement" became a milestone not only for recognising sustainable development as the only reasonable solution to tackle the many negative impacts of climate change but also for associating it with several goals to which public and private actors committed.

Most of the Sustainable Development Goals (SDG) focus directly on people-related topics (poverty, hunger, health, education, gender, inequalities) and their activities (work, economy, consumption, and production) or the biosphere (life on land or below water, climate). But one of them directly aims at man-made habitat: the cities. The aim is to "make cities and human settlements inclusive, safe, resilient and sustainable".

Cities are recognised as places where the battle for sustainable development will be won or lost. They became a crucial player in this endeavour due to the importance that they have acquired in recent decades. It is estimated that more than 50% of the world's population now live in cities, and the expectation is that this may increase to 70% by 2050. Cities are, and will continue to be, seen as a place of opportunities: jobs, quality of life, culture, or business. This concentration of people in a limited amount of space (cities account for no more than 3% of the land in the world), which constitutes an urbanisation process, raises numerous challenges; from water scarcity to pollution, from mobility to energy consumption, from food supply to informal settlements, from overburden of infrastructures to increased exposure to risks (natural or man-made) (UN-Habitat, 2022).

To overcome all these challenges (and others), a holistic view of the cities and their several systems is required. But also an understanding of the different strategic options and tactical moves that can contribute to increasing urban sustainability, the efficiency of the systems, and the citizens' well-being. The significant events happening in 2015 (Paris Agreement and SDG), plus the awareness of the importance of cities in the future of the planet and the need for professionals able to have a different view on what happens in cities, were the basis for the creation of the undergraduate degree in Sustainable City Management which is taught at the Institute of Engineering of the Polytechnic Institute of Coimbra (ISEC-IPC) since 2018.

In the defining document of the course, it is stated that: "The one who completes a degree in Sustainable City Management will be ready to respond to the challenges associated with a growing urbanised world. Therefore, the locus of their professional action will be the built environment that constitutes the urban areas and its diverse components, with a special emphasis on their management, operation, and optimisation, from a sustainable perspective." From its inception, the undergraduate degree wanted to provide a strong practical emphasis grounded on a solid theoretical background. The focus was on operating, managing, and improving urban systems and infrastructures, keeping sustainability criteria in mind. Hence, the primary learning outcomes were set as follows:

- "To acquire knowledge related to urban sustainability, as well to the existing risks in an urban environment;
- To develop competencies associated with the management, operation and rehabilitation of urban systems and infrastructures;
- To develop competencies associated with the rehabilitation of the built environment (and the soil where it stands), including repair of structures and other constructive elements, improvement of comfort standards, reinforcement of foundations, and introduction of new materials;
- To develop competencies in project and operations management, communication, collaboration and teamwork."

Due to the transversal approach adopted, the syllabus covered diverse topics that included foundations, construction, urban planning, mobility, waste, project management, infrastructures, risks, or GIS (Geographic Information System), among others. But, besides the degree's content, great importance was given to the teaching-learning methods that needed to encourage a personalised approach and meet each student's interests and learning process.

2.2 The importance of geotechnical knowledge in the day-to-day life of a city

Ecosystems provide a wide range of benefits and services for the well-being of humankind that can be grouped into four categories (Millennium Ecosystem Assessment, 2005). In each category, several functions may be identified, as described below (Millennium Ecosystem Assessment, 2005; Adhikari & Hartemink, 2016):

- Provisioning: food, fresh water, wood and fibre, fuel, raw materials, ornamental resources, medicinal resources;
- Regulating: climate regulation, flood regulation, disease regulation, water purification;
- Cultural: aesthetic, spiritual, educational, recreational, ecotourism;
- Supporting: nutrient cycling, soil formation, primary production, and human infrastructures.

These ecosystem services can be related to almost all the United Nations Sustainable Development Goals for 2015-2030. Indeed, Keesstra et al. (2016) state that only goals 5 (achieve gender equality and empower all women and girls), 10 (reduce inequality within and among countries), 14 (conserve and sustainably use the oceans, seas and marine resources for sustainable development) and 17 (strength the means of implementation and revitalise the global partnership for sustainable development) cannot be related to ecosystem services. According to the European Commission (EC, 2006), soils and rocks contribution to ecosystem services may be divided into seven groups of functions: i) biomass production (including agriculture and forestry); ii) storing, transforming and filtering substances, water and nutrients; iii) biodiversity; iv) physical and cultural environment for humankind and human activities; v) source of raw materials; vi) acting as carbon pool, and vii) geological and archaeological heritage.

Several soil sciences contribute to understanding and enhancing soil and rock functions, namely, agronomy, ecology, hydrology, and climatology (Keesstra et al., 2016). Although Keesstra et al. (2016) do not refer to it, geotechnical engineering should also be considered since the utilisation of soils and rocks requires technical design to ensure safety when citizens take advantage, directly or indirectly, of the infrastructures built on, under or with soils and rocks. Thus, the knowledge of soils and rock properties is fundamental. In urban areas, soil and rock functions are provided by parks and gardens, which contribute to air quality regulation, water regulation, local climate regulation, cultural heritage, recreation and education (Millennium Ecosystem Assessment, 2005). Depending on the city's location, other functions may be added, such as storm and wave protection and erosion control.

The ability of soils and rocks to perform the aforementioned functions depends on their intrinsic or situational characteristics, among which stand out (Adhikari & Hartemink, 2016): particle size distribution, bulk density, hydraulic conductivity and infiltration, soil temperature, soil porosity and air permeability, water content, soil *pH*, particles mineralogy or soil biota. In addition to these parameters, one may add soil and rock strength and deformation parameters. These parameters might be grouped under biological, chemical and physical indicators, as Bünemann et al. (2018) stated.

Humankind evolution and population growth have been increasing pressure on ecosystems, resulting in several soil threats (Bünemann et al., 2018), namely erosion, soil organic matter decline, contamination, sealing, compaction, biodiversity loss, salinisation, landslides and floods. According to the United Nations (2018) and World Bank (2022), 55% of the current population lives in cities, and 70% of the world population is expected to live in cities by 2050. Based on this data and previsions, soil threats and related phenomena will likely increase, thus justifying the inclusion of subjects related to geotechnics in sustainable city management. Additionally, natural hazards, such as those resulting from seismic or volcanic activity, should also be considered when planning and thinking about cities.

Given the above, the education offered in the bachelor's degree in Sustainable Cities Management includes three mandatory subjects: Soils and Rocks, Study and Behaviour of Soils, and Foundations and Land Support; one optional subject, Improvement and Reinforcement of Soils and Foundations as well as some modules integrated into other subjects, such as Landslides in Urban Risks. The syllabuses of these subjects contemplate a wide range of soil and rocks topics, such as:

- geology for engineering: Earth formation, plate tectonics, rocks cycle;
- environmental geotechnics: soil contamination, soil and rocks as construction material, quarries and sandpits, ecosystems, blue and green infrastructures, geosynthetics, ground improvement;
- energy and climate change: geothermal energy, urban floods, coastal erosion, urban heat island, air quality, waste management;
- soil testing: recognition and prospecting, laboratory testing, in situ testing;
- soil mechanics: soil identification and classification, hydraulic conductivity, shear resistance, compressibility and consolidation;
- geotechnical engineering: earth retaining structures, shallow and deep foundations, pathologies and foundations reinforcement;
- geotechnical risks: seismicity, liquefaction, quickclays, quicksands, landslides, piping.

These subjects and all the topics taught intend to provide students skills and competencies that allow them to understand or to know how to carry out studies on soils and rocks, how society can take advantage of these materials using nature-based solutions, how soils and rocks respond to external loads, what technical or environmental solutions are available, what are the risks populations face depending on their geographical position. Some of these topics include studying the physical properties of soils and rocks and technical knowledge. However, there is a clear distinction between the knowledge transmitted to a future engineer, who may be responsible for the design and construction of geotechnical structures, and a manager, who may be responsible for the idealisation, promotion or management of geotechnical solutions to face new future challenges in a world in constant and rapid change.

Among these challenges, climate change and its related phenomena should be highlighted. According to the last Intergovernmental Panel on Climate Change (IPCC), several countries or geographical areas have already demonstrated weather and climate changes. For example, since 1950, hot extremes have been recorded in all states-member of the European Union, leading to an increase in ecological drought in the Mediterranean countries and Western and central Europe (Intergovernmental Panel on Climate Change, 2021). Also, except for Mediterranean countries, the rest of Europe has observed changes in heavy precipitation. The extreme events hugely impact ecosystems and human systems (Intergovernmental Panel on Climate Change, 2022a). Indeed, an increase in adverse impacts on health and well-being has been recorded in Europe, namely on cities, settlements, and infrastructures due to inland flooding.

Based on the five Shared Socio-Economic Pathways (SSP) presented by Intergovernmental Panel on Climate Change (2021), it is expected that, for global warming levels up to 2 ºC, hot extreme temperature events that traditionally happen once every 10 and 50 years now occur up to 5.6 and 13.9 times. It is also expected an increase of heavy 1-day precipitation events, passing from a frequency of once per 10 years to 1.7 times in 10 years. It should be noted that these events will likely be 14% wetter than now (Intergovernmental Panel on Climate Change, 2021). Several climate responses and adaptation options are available to face current and expected extreme events. These solutions are transversal to several scientific domains in which geotechnics can significantly contribute, namely in managing land and ocean ecosystems and urban and infrastructure systems (Intergovernmental Panel on Climate Change, 2022a). Geotechnical knowledge is fundamental when proposing or idealising solutions for (Intergovernmental Panel on Climate Change, 2022a, b):

- coastal defence;
- water use efficiency and water resource management;
- sustainable urban drainage systems;
- implementation of green and blue infrastructures;
- sustainable urban and land planning;
- district heating and cooling networks (geothermal energy);
- waste minimisation and management;
- on-site and nearby production and use of renewables (geothermal energy);
- change in construction methods, materials and circular economy;
- carbon capture and storage;
- disaster risk management, including early warning systems;
- nuclear waste disposal;
- others.

The idealisation of solutions to urban issues, the enhancement of environmental approaches (green corridors), the proposal of mitigations and adaptation solutions to climate change (urban flood, urban heat island, carbon capture and storage), the study current state of the art of recent application fields, the forecast of future geotechnical challenges (space mining, for example), the identification of urban areas likely to be intervened for the implementation of green infrastructures or understanding the reasons for better or worse acceptance of geotechnical solutions (such as geothermal) are some of the assignments and challenges proposed in two of the subjects mentioned above taught in the bachelor's degree in Sustainable City Management. In Soils and Rocks and Study and Behaviour of Soils subjects, the continuous assessment methodology foresees group work to be carried out on these and other topics of geotechnical interest.

3. Co-creation approach in classroom

Kambil et al. (1999) presented, for the first time, the concept of co-creation to express the interactions between companies and consumers, generating added value for all the stakeholders and introducing new dynamics between them. Although many definitions have been proposed since then, all share the same characteristics (García Haro et al., 2014): i) co-creation is a process that involves companies and users; ii) the activities require the collaboration of the stakeholders; iii) co-creation aims to create value for both stakeholders. It is also important to mention that a co-creation process should also be perceived as a stimulus to innovation and the development of new solutions (Orcik et al., 2013). The European Commission (2021) considers that co-creation processes are based on innovative approaches, allowing participants to interact from different backgrounds. Also, policymakers have encouraged co-creation processes (Chryssou, 2020). In a global society in which companies intend to benefit from a faster transfer of knowledge (Polese et al., 2021) and universities seeking opportunities to promote research, improve metrics and involve students in the market, co-creation processes are an asset for all parties involved (Cohen et al., 2002). However, partnerships established in co-creation processes depend on some factors to be successful (Rybnicek & Königsgruber, 2019), namely:

- structural, such as bureaucracy, organisation flexibility and decision-making process;
- of commitment, which is related to how much the involved parties identify themselves with the process and its objectives;
- reliability;
- willingness to change, that is, the ability to adapt to different circumstances being receptive to change;
- communication and regular information sharing.

Finally, the outcomes of co-creation challenges depend on the participants' creativity. Although creativity can be identified at any age, due to the curiosity that characterises younger people, the involvement of higher education institutions, where thousands of young people study, in co-creation activities emerges as a logical consequence for developing future solutions and knowledge transfer. During the process, students will experience three dimensions (Dziewanowska, 2018). Under the co-production dimension, which is related to what students really do in the process, they have to learn how to dialogue, control the process, and access and manage information. The second dimension is the experience, which is related to involvement and intellectual stimulation. The last dimension is the relations created among the students and their interaction with others, and how they share the knowledge.

Implementing active learning methodologies alone, such as co-creation approaches, does not guarantee academic success or student participation. According to Vanishree & Tegginamani (2018), successful project-based learning requires, among other assumptions: i) students' attendance and punctuality; ii) steps of the methodology cannot be skipped; iii) the process should be evaluated regularly; iv) students should be proactive and not wait for facilitator to provide all the needed information and details. Not the least, the triggers of the methodology (urban challenges) must stimulate students' motivation and interest in solving the presented challenges. Of course, as with any other pedagogical approach, the co-creation methodology has disadvantages. Concerning the acquired knowledge, Jones (2006) states that it may be less organised than knowledge resulting from traditional learning. Also, the time required for a full engagement of students may not be compatible with crowded curricula (Jones, 2006), being faculty-intensive and time-consuming (Ribeiro, 2011; Abdelkarim et al., 2018). For institutions, implementing such a methodology requires investment in human and physical resources (Pawson et al., 2006). The faculty's educational philosophy can only be changed by training and a differentiated learning environment; for example, more flexible classrooms that provide a creative atmosphere are needed.

The co-creation methodology implemented in the IPC is based on the Demola model developed by Demola Global. This international organisation facilitates co-creation projects between higher education institutions and public and private entities. The group was established in Finland in 2008 and currently operates in 18 countries worldwide. This program brings together students and teachers as facilitators and, depending on the challenge and objectives, it may include organisations. Ideally, the student team should be transdisciplinary to enhance strategic thinking based on the perception of the new generations and, thus, provide solutions to real challenges/problems posed by organisations, when involved, or by the teacher, as illustrated in Figure 1.

As the present study was conducted at the classroom level, the implemented co-creation model has to be adapted. The student team is comprised of only students who attended the Study and Behaviour of Soils course. During the fall semester of the academic year 2022/2023, 24 students in the second year of the bachelor's degree in Sustainable Cities

Management were invited to participate in a co-creation process as part of the continuous assessment methodology. Among the 18 students who were effectively evaluated (6 of the students gave up), most are male, counting 83.3% against 16,7% of females. All the students are between 19 and 23 years old, most of them being 19 years old (66.7%). The weekly workload of the course is 3.5 hours, and the semester lasts 15 weeks. During the implementation of the co-creation process (8 weeks), the first 1.5 hours of class were dedicated to the co-creation, introducing the weekly task and allowing the groups of students to start working on it. During the remaining class time, the syllabus planned for the class was presented, and expository sessions were interspersed with laboratory and problem-solving moments. The class was divided into three groups of 6 students. Given the conditions of access to this bachelor's degree, different paths in high school could be identified. Thus, it ensured the greatest heterogeneity in the groups to improve the creative process, which took place, as stated before, over eight weeks and followed the double diamond model. This model, which was first proposed by Banathy (1996), comprises two distinct phases: "Discovery" and "Creation" (Figure 2).

The "Discovery" stage of the process, which is the first stage, is intended for students to gather as much information as possible on the challenge topic. In the 2022/2023 academic year, under the motto of the European Commission, the main topic of the challenge was "Green infrastructure project: a network of healthy ecosystems provides alternatives to traditional grey infrastructures". Once the groups have been formed, each group proposed a challenge integrated into the main topic of the process, that should agree with the objectives of the bachelor's degree. Although the outcomes of each challenge are beyond the scope of this study, the proposed challenges were:

- study of solutions for the occurrence of floods in Praça 8 de Maio, in Coimbra;
- integration of green infrastructures in the Norton de Matos neighbourhood (Coimbra) to collect rainwater and return green spaces to residents;
- model of the use of green infrastructure to the reuse of rainwater in typical dwellings.

Group formations and challenges proposal, which took place during the first week of the co-creation process, represent the first task of the methodology. Through the following three

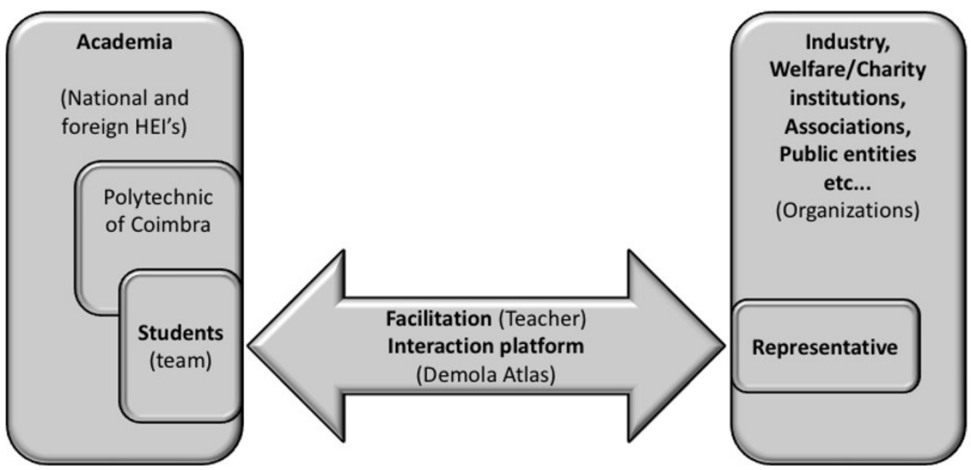


Figure 1. Demola innovation co-creation model.

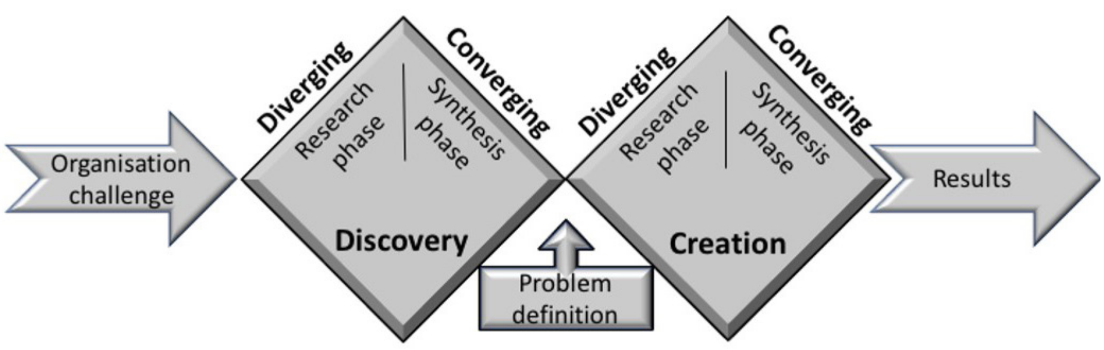


Figure 2. Double diamond model applied to innovation co-creation process (adapted from Banathy, 1996).

weeks, students carry out several tasks, which can be divided into two distinct phases: i) the research phase and ii) the synthesis phase (Figure 2). During weeks 2 and 3, students must list all the stakeholders that directly or indirectly can influence or be influenced by their challenge topic. After this long list, students must identify three to five stakeholders on which the students' research will focus. They will identify potential interviewees whose knowledge of the topic will complete the information acquired from reading and analysing articles and all other relevant sources of information. Despite the time devoted to projects in class, students must continue the work at their own pace. Thus, it is recommended that all the collected information be compiled in collaborative and visual platforms (e.g., virtual boards, shared documents). The use of virtual and blackboards facilitates the tasks of the synthesis phase of the "Discover" stage of the process. In the synthesis phase, during weeks 4 and 5 of the process, students are invited to complete empathy maps where each target stakeholder is characterised based on what it says, does, feels or thinks. When synthesising all the information, students must identify design insights, which are outcomes that stand out from the rest of the information more conjectural. After completing the previous tasks, students may write their midway report. In addition to empathy maps and design insights, the research results, as well as the evidence collected during the interviews, allow students to have a macro understanding of the topic. All this information is summed up in a PESTLE report in six dimensions: political, economic, social, technological, legal, and environmental.

During the "Discovery" stage, the teacher acts as a facilitator, offering assistance and advice while working on the team's motivation and fellowship. The facilitator also: i) presents and proposes several tools for collaborative work; ii) helps to separate relevant sources of information from less reliable ones; iii) moderates and schedules weekly meetings where the entire team should be present, which, usually, takes place during classes. If the challenge involves third parties, the facilitator enhances contact between the representative of the organisation and the students, promoting virtual or physical meetings. This supporting role gains relevance during the second part of the challenge: the "Creation" stage. To not conditionate students' creative process, the facilitating teacher and the organisation's representative (if any) have limited interference during this stage. The facilitator supports the team by promoting interviews with specialists/researchers on the challenge topic and coordinating field trips to research, innovation centres, or other places. These activities, which also provide a creative atmosphere within the team, ensure that the team's vision has not been unsuccessfully explored. The creative atmosphere supplements the atmosphere of trust between the students, allowing the sharing of opinions, thoughts, and skills without fear (European Commission, 2021).

The "Creation" stage can be seen as the creation phase itself, in which, based on the knowledge gathered during the "Discovery" stage of the co-creation process, students carry out speculative work, identifying alternative outcomes to the proposed challenge. The transition from the current situation or state of the art to a probable future is supported by several thinking tools, which rely on identifying "weak signals". Many definitions for weak signals may be found in the literature. In the present work, the authors follow the definition from the compilation proposed by van Veen & Ortt (2021) who refer: "*a perception of strategic phenomena detected in the environment or created during interpretation that are distant to the perceiver's frame of reference*". I.e., weak signals are singularities that take place everywhere and seem unlikely and/or cause bewilderment. Each student is invited to identify at least one weak signal during week six of the co-creation process.

After identifying those weak signals, students can start to define their speculative design by asking two types of questions: What if…?, and How might we…? These questions are part of a creative thinking methodology whose application makes it possible (Lahiri et al., 2021): i) to frame complex problems, ii) to discover needs still unknown, and iii) to propose more appropriate solutions. These questions should be provocative and bold and cannot be limited to factual situations that may or may not happen, such as political, economic, social or any other constraints. The speculative questions and the proposal of future scenarios are the assignments for week 7 of the co-creation methodology. Based on the outcomes of the previous weeks and the speculative questions, students suggest three scenarios, identifying the winds of change and the possible effects of the proposed future vision. The creative stage (Figure 2) ends with the elaboration of a future report (week 8), which compiles all the information contained in the midway report as well as all the speculative work carried out in this second stage, highlighting the future scenarios, which are the primary outcomes of the co-creation process.

After delivering the future report, a third and final stage occurs: the presentation of the team's outcomes. In a classroom context, such as the experiment carried out in the course of Study and Behaviour of Soils of the bachelor's degree in Sustainable City Management, this presentation assumes the characteristics of an academic presentation, with the facilitator teacher encouraging the diversification of instruments to support the presentation, such as models or videos. However, this pitch may also occur for broader audiences, namely final pitches and national or international batches, such as those that the IPC and other Portuguese polytechnics have promoted since 2021. When organisations are involved, the project outcomes are first presented to them. Table 1 summarises the main tasks proposed to all the groups during the co-creation process.

4. Outcomes of co-creation implementation

4.1 Research design

The co-creation pedagogical approach that was applied, and whose description and results are presented in this study, has been implemented in the course of Study and Behaviour of Soils, a subject of the second year, fall semester. The students who participated in this initiative were also asked, in the previous academic year (first year, spring semester), in the course Soils and Rocks, to prepare and present an assignment to be carried out in groups. In this last course, the methodology followed a more traditional approach, in which all information was provided at the beginning of the year. Based on the information provided, students should work autonomously, setting their own pace and goals. Only the final date of the presentation has been defined. Finally, it should be noted that, in both cases, the maximum grade for teamwork was 5 points out of 20.

Once the outcomes of the co-creation projects were presented, students were asked to answer a final survey to evaluate their satisfaction level with the methodology and their perception of the development of various social, personal, and professional skills. Since the students had already attended another subject in the field of geotechnics, questions aimed at a direct comparison of pedagogical methodologies were also prepared.

The questionnaire counted eighteen questions. The first set of questions comprised eight questions about the students' perception of the skills developed during participation. The second set of questions (six questions) referred to applying the co-creation methodology in a classroom context, aiming to evaluate and understand the degree of satisfaction with the process and the impact of such a pedagogical approach on students. A third set with two questions intends to directly compare co-creation methodology with traditional assignments. Finally, a last set of questions has two open-ended questions to collect information about difficulties felt by the students during the co-creation process and improvements that can be made to this pedagogical approach. Except for the two last questions, the questionnaire was applied on a multiple-item scale (from 1 to 7), Likert type. On this scale, 1 represents "completely dissatisfied" or "strongly disagree", while 7 suggests "completely satisfied" or "strongly agree".

4.2 Results and discussion

4.2.1 Soft and scientific skills improvement

Student's perspectives about the competencies developed during the implementation of the co-creation methodology are shown in Figure 3. In an overall analysis, it is easy to conclude that students recognise that their skills improved during the process, namely the so-called 21st Century skills (World Economic Forum, 2016). According to this document, the 21st-Century skills may be divided into three

Table 1. Co-creation methodology tasks timetable.

Timetable		Tasks
Discovery Stage	Week 1	Selection of working groups and definition of the challenge (theme chosen within the syllabus of the curricular unit)
	Week 2	List of Stakeholders, potential interviewees
	Week 3	Conducting interviews, questionnaires and collecting information / compiling information
	Week 4	Empathy maps / Design insights / PESTLE analysis
Creation Stage	Week 5	Midway report
	Week 6	Signals (3 main takeaways)
	Week 7	Speculative questions. Future Stakeholders - future changes – future scenarios
	Week 8	Final report (Assessment)

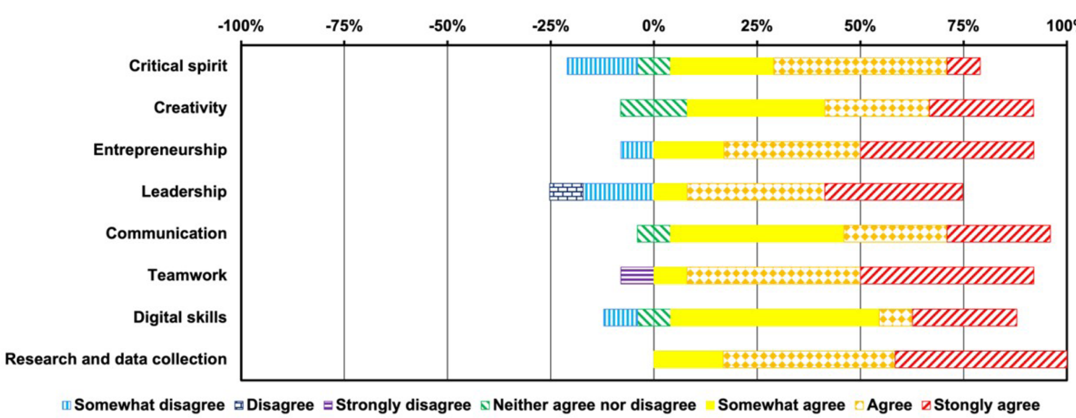


Figure 3. Student's perspective on skills and competencies developed during the implementation of co-creation methodology.

groups: i) foundational literacies, ii) competencies, and iii) character qualities. The second group of skills has the most cited competencies, also known as the 4C: critical thinking, creativity, communication and collaboration. Concerning creativity and communication (Figure 3), students have a positive perspective on the contribution of this pedagogical approach to developing these competencies, reaching 83% and 92% of positive opinions for creativity and communication, respectively. Notably, 50% of students answered "agree" or "strongly agree" in both competencies.

Although 75% of the students also have a positive perception of the influence of co-creation methodology on the development of their critical thinking, 17% of students "somewhat disagree", and 8% have a neutral opinion. Finally, 8% of students consider that their collaboration competency (teamwork in Figure 3) did not improve during the process, which contrasts with the opinion of 84% of their colleagues who answered "agree" or "strongly agree". One possible reason to justify these less favourable standpoints may be related to the working group itself. As stated in Section 3, the elements of the groups were chosen to guarantee the greatest possible heterogeneity, and this choice was not always in line with the personal affinities of the students, leading to misunderstandings between the elements of the group. This conclusion is supported by the suggestions and difficulties presented by the students in the two last open-ended questions of the survey. The impossibility of choosing group members and the problematic relationship between some members were issues mentioned in 33% of the comments written by students. Another interesting deduction is that, despite the experience acquired in online work during Coronavirus Disease 2019 (COVID-19) lockdowns, the difficulties in gathering the group members and the physical distance between the places of residence were mentioned in 13% of the comments presented.

The character qualities, the third group of skills valued by World Economic Forum (2016), relate to how students deal with changes in their surroundings. Among the listed qualities, one may identify initiative, adaptability and leadership, which were also considered in the student survey. When asked if co-creation methodology helps students to increase their entrepreneurship (Figure 3), which can be understood as initiative, 92% of students have a positive perspective (33% agree and 42% strongly agree). Students' adaptability to new challenges may be measured through their ability to research and collect data to face unforeseen events or situations. Students' opinions could not be enlightening, with all the students having a positive perception, 50% of them strongly agreeing with the contribution of this pedagogical approach to increase this quality. The worst results are related to leadership; 25% of students perceived that the quality was not improved during the process. To conclude the analysis of the skills developed throughout this methodology, one may refer to the digital skills, which can be encompassed in ICT literacy (Information and Communication Technology), a core skill of the foundational literacies, according to the World Economic Forum (2016). 83% of students consider participating in the project improved their digital skills.

The results above align with the study conducted by Costa et al. (2021) with 87 students from 19 different countries across all the higher education levels. According to Costa et al. (2021), based on a 4-point scale, creativity, teamwork, leadership, and entrepreneurship reached 3.5, 3.6, 3.4, and 3.4 points, respectively. It should be noted that similar to the results of this study, students' perception of leadership skills is not as favourable as the other skills. On the other hand, in Costa et al. (2021) study, the students concluded that co-creation methodology enabled them to develop teamwork skills.

4.2.2 Academic performance

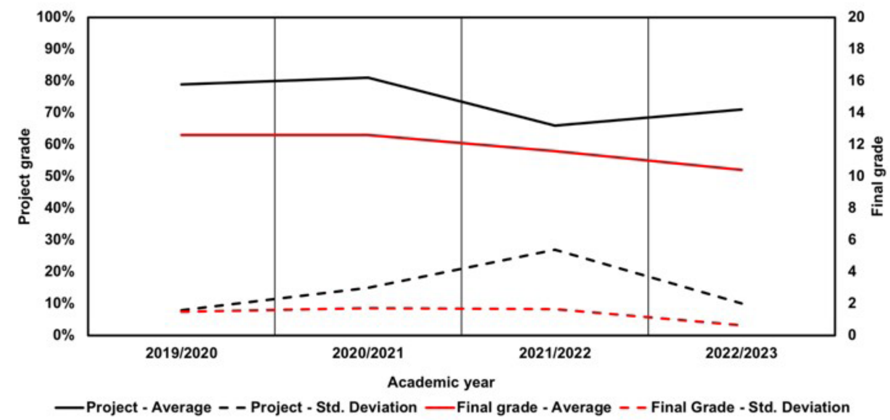
Implementing a co-creation methodology as a pedagogical approach is intended to provide a more favourable knowledge acquisition and transfer environment. Thus, it is also essential to evaluate students' academic results. For this, in addition to the average data of the academic year 2022/2023, to which the survey results relate, the results are also presented since the opening of the bachelor's degree in Sustainable City Management. It should be noted that, during the COVID-19 pandemic, although Study and Behaviour of Soils classes were always held face-to-face (since it is a subject from the fall semester), students were affected by the lockdowns that occurred in Portugal in 2020 (March to May) and 2021 (January to March). Starting by analysing students' performance in the subject assignment/project, it can be seen in Figure 4a that the implementation of the co-creation methodology allowed recovery from the significant decrease of students' marks (14%) registered between 2020/2021 and 2021/2022. Another interesting result is the decrease in the standard deviation resulting from the group formation process.

Contrary to the improvement of results in continuous evaluation, students' final grade, which comprises the assignment/project and written examinations, is still decreasing. It should be noted that although the implementation of the co-creation methodology changed, its weight in the final grade remained the same, that is, 25% of the subject's final grade. The authors currently have no explanation for this observation. However, the social and school effects of decisions taken during the COVID-19 pandemic cannot be disregarded. Interestingly, despite the decrease in the average students' final performance, the number of students failing the subject decreased from 36% to 25%, as shown in Figure 4b. This improvement may be related to the increase in class attendance recorded in 2022/2023. Comparing this assiduity data with data referring to the subject of Soils and Rocks attended by the same students, there is a 5% increase in class attendance.

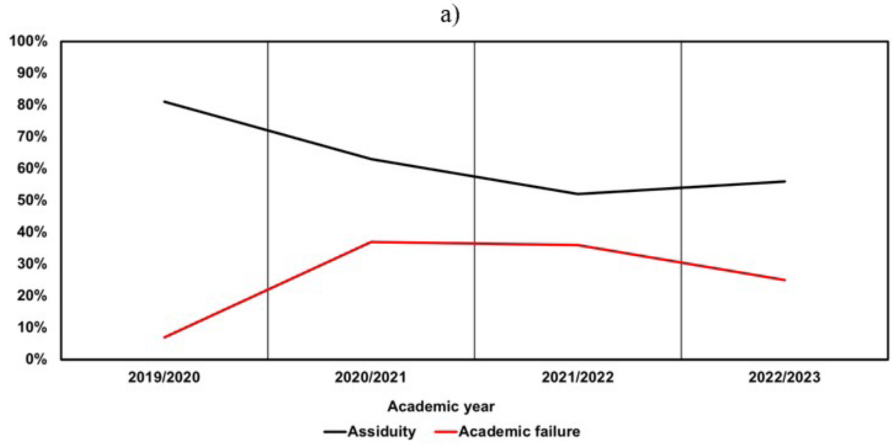
4.2.3 Overall evaluation of the methodology

From a pedagogical point of view, the implementation of co-creation methodology in a classroom context has also been evaluated through a second set of questions, whose results are summarised in Figure 5. As it can be seen, according to the students' perspective, the overall evaluation is positive. In particular, 84% of students are satisfied with participating in the project and the methodology. Also, 92% of the students would like to see this methodology applied to other subjects, of which 75% answered "strongly agree". These results are corroborated by the perception of the students who participated in the study of Costa et al. (2021), in which participation in the project was rated 3.8 out of 4.0, and 93% of students would recommend other colleagues to participate in such an experience.

According to the students, the conduction of classes and lessons is positively affected by implementing this pedagogical approach: 92% of students answered that class productivity and the dynamics of the classes themselves improved (Figure 5). Indeed, Araújo et al. (2021) state that when co-creation methodology is implemented, students tend to be more active in the learning process. However, the students have identified some limitations related to the task timetable (Table 1). A small



a)



b)

Figure 4. Students' academic performance: (a) scientific and technical evaluation; (b) academic data.

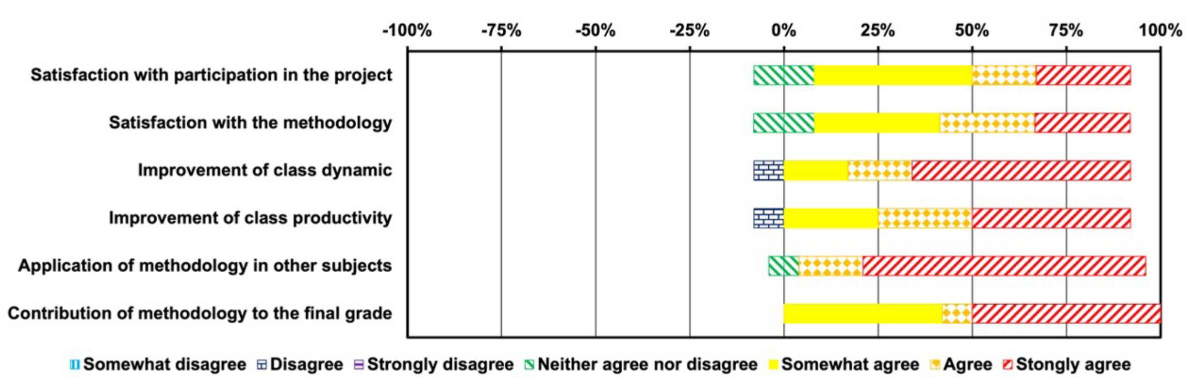


Figure 5. Students' perspective of the benefits of implementing co-creation methodology in the classroom context.

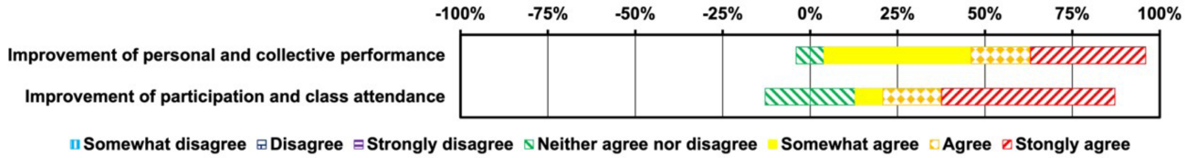


Figure 6. Students' opinion on the implementation of the co-creation methodology, comparing two subjects in the geotechnics field.

percentage of students (6%) point out the need for more delivery times to better organise their research and teamwork. 20% of students also identified the need for diversification of learning tools during the implementation of the process, such as the inclusion of more laboratory tasks, field visits and/or the use of more audio-visual means when presenting and explaining the geotechnical concepts of the course syllabus.

An essential outcome of this set of questions is students´ perception concerning the contribution of this pedagogical approach to their final grade in Study and Behaviour of Soils. All the students positively perceive the benefit of co-creation in the achieved results. Although the average final grade is still decreasing compared to the previous academic years, academic failure decreased by 11%. This perception can be understood by considering the academic results of the students in the subject Soils and Rocks, which the same students attended the previous semester. Indeed, after all the exam calls that ISEC-IPC provides to all its students, 61% of students failed, which is 2.5 times more than the failure rate obtained in Study and Behaviour of Soils. This observation was, in fact, at the origin of the adoption of this new pedagogical approach.

These conclusions are reinforced by the last set of questions, intended to directly compare Soils and Rocks (spring semester of the academic year 2021/2022) and Study and Behaviour of Soils (fall semester of the academic year 2022/2023). As stated in Section 4.1, the continuous evaluation of Soils and Rocks presupposes a group assignment with the abovementioned characteristics. As Figure 6 shows, students consider that their personal and collective performance improved (92%). This result agrees with the engagement outcomes presented by Araújo et al. (2021). When comparing the average final grade of students, there is an increase from 10.1 to 10.4 (out of 20 points). Also, the standard deviation decreases from 2.13 to 0.65. This reduction translates, understandably, to a decrease in higher grades but also an increase in the lower grades of students. The average grade in the proposed group work in Soils and Rocks is 75%, slightly higher than the 71% obtained in Study and Behaviour of Soils. However, once again, the standard deviation decreases from 18% to 10%. This reduction, as well as the one verified in the average final grade, may explain students' perception of their performance, namely if students had reached the lowest grades in Soils and Rocks. According to 26% of the students, implementing the co-creation methodology in a classroom context had a neutral effect on increasing participation and class attendance (Figure 6). This contradicts the data collected on the ISEC-IPC academic management platform, as illustrated in Figure 4b.

5. Conclusions

Humankind's evolution is at the origin of several social, economic and environmental issues in current times, such as climate changes, land use and (mega)city management. Aiming to prepare citizens to face these challenges by idealising, providing or applying solutions, the Institute of Engineering of the Polytechnic Institute of Coimbra (ISEC-IPC) proposed a new bachelor's degree in Sustainable City Management, which has been training and preparing students since 2018. Among the numerous topics covered, students attend mandatory or optional geotechnics courses, learning basic concepts of soil mechanics, environmental geotechnics, ecosystem function of soils, soil improvement, and natural capital, among others.

Aiming to increase students' performance in a particular subject of the undergraduate degree, Study and Behaviour of Soils, and taking into account recent results in another geotechnics-related subject (Soils and Rocks), a new pedagogical approach has been implemented in the academic year 2022/2023: co-creation process. This methodology, which aims to develop and propose innovative solutions to solve current and future geotechnics-related issues of cities, is presented, and some tasks that can be proposed to the students are fully described in this study.

This implementation is an undergoing pedagogical experiment and requires enhancements, such as more extended deadlines and diversification of learning tools. Nevertheless, this case study provides a positive perception of students, aligning with previous studies in different fields. Generally, it is possible to highlight the following findings:

1. 75% of students have agreed, although at different levels, that implementing a co-creation methodology helps improve their soft skills. The most deviant result refers to teamwork, which several students have highlighted in the open-ended questions;
2. When examining students' final results, although the final grade did not improve, the student failure rate decreased by 11%, and the lowest mark increased. Academic data also reveal that class assiduity increases, although students do not have this perception;

3. 92% of students want this methodology to be applied to other subjects. 84% of students concluded it is more advantageous and leads to better personal and collective performance.

The present study corroborates previous research by identifying the benefits of co-creation methodology as a pedagogical process to enhance soft skill acquisition and students' motivation and participation, hopefully leading to better grades. However, geo-environmental education also requires hard skills, such as basic and advanced knowledge of permeability, shear strength and compressibility. The next challenge is to adapt this methodology to captivate the attention of students, who have shorter concentration times, less tolerance for delayed results and a growing digital presence, to continue training and educating the next generations of professionals in geotechnics. To achieve this purpose, the authors suggest to:

- Replicate the double diamond model (Banathy, 1996) for different topics of the course syllabus;
- Introduce a blended learning approach during the methodology's discovery phase. Using e-activities (digital environment) may enhance students' learning process, according to their own pace and learning profile, to acquire the scientific or empirical background needed. The design of these e-activities should contemplate all the principles proposed by Salmon (2002). By implementing these e-activities, more contact hours can be dedicated to practical or laboratory implementation;
- In the creation phase, which should occur only in a physical environment (classrooms), developing problem-oriented learning approaches allows students to apply the recently acquired knowledge. Through collaboration, students can achieve deeper and longer-term retention, as suggested by the learning pyramid model.

Declaration of interest

The authors have no conflicts of interest to declare.

Authors' contributions

Vera Cristina Ribeiro: conceptualization, validation, writing - original draft preparation, writing - reviewing and editing. Sara Isabel Azevedo Proença: data curation, funding acquisition, project administration, writing - reviewing and editing., visualisation. Luis Manuel Araújo Santos: resources, formal analysis, writing - original draft preparation, writing - reviewing and editing. João Armando Pereira Gonçalves: writing - original draft preparation, writing - reviewing and editing.

Data availability

The datasets presented and analysed throughout the study are available upon request to the corresponding.

List of symbols and abbreviations

4C 21st century skills	critical thinking, creativity, communication and colaboration
pH	potential of hydrogen
COVID-19	Coronavirus disease 2019
GIS	Geographic Information System
ISEC-IPC	Institute of Engineering of the Polytechnic Institute of Coimbra
IPC	Polytechnic Institute of Coimbra
IPCC	Intergovernmental Panel on Climate Change
SDG	Sustainable Development Goals
STEM	Science, Technology, Engineering and Mathematics

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