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A Case Study on Emerging Learning Pathways in SDG-Focused Engineering Studies through Applying CBL

Daina Gudonienė [1], Agnė Paulauskaitė-Tarasevičienė [1], Asta Daunorienė [2,3] and Vilma Sukackė [4,*,†]

[1] Faculty of Informatics, Kaunas University of Technology, Studentų St. 50, LT-51368 Kaunas, Lithuania; daina.gudoniene@ktu.lt (D.G.); agne.paulauskaite-taraseviciene@ktu.lt (A.P.-T.)
[2] EDU_Lab, Kaunas University of Technology, K. Donelaičio St. 73, LT-44249 Kaunas, Lithuania; asta.daunoriene@ktu.lt
[3] School of Economics and Business, Gedimino St. 50-319, LT-44239 Kaunas, Lithuania
[4] Faculty of Social Sciences, Kaunas University of Technology, Arts and Humanities, A. Mickevičiaus St. 37, LT-44244 Kaunas, Lithuania
* Correspondence: vilma.sukacke@ktu.lt
† The study has been conducted within the ECIU University, which is European university where learners and researchers cooperate with cities and businesses to solve real-life challenges. The ECIU University is an EU-funded initiative of 12 European universities www.eciu.org.

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Abstract: Recently, a growing number of Higher Education institutions have started to implement challenge-based learning (CBL) in study processes. However, despite the growing Higher Education attention to challenge-based learning, research on the method, especially in Engineering education, has not been extensively conducted and made publicly available to the community of researchers and teaching practitioners. To bridge this gap, this paper provides a case analysis of implementing challenge-based learning in a Master's degree program for engineering students, aiming to highlight the main aspects of combining challenge-based learning and Sustainable Development Goal 11 (SDG 11), namely sustainable cities and communities. The findings are consistent with previous CBL studies revealing positive benefits of implementing the method; however, the paper adds novelty by showcasing the learning pathways that emerge to learners and teachers when CBL is implemented in an SDG-11-focused course.

Keywords: challenge-based learning; SDG learning; sustainability; higher education; learning pathways

1. Introduction

The United Nations Educational, Scientific, and Cultural Organization (UNESCO) emphasizes the role of Higher Education institutions in the global development agenda, which endeavors to combat such issues as poverty and address various social needs such as education, health, social protection, job opportunities, climate change, and environmental protection [1]. Due to the interdisciplinary study programs and research as well as the capacity to develop innovative solutions to global and local problems, Higher Education institutions play a key role in driving the ambitious sustainable development goals towards real practice. Moreover, Higher Education institutions are a pillar in embedding different teaching and learning strategies across the curriculum. They also focus on student-centered learning principles and different didactic methods to reflect the strong interdisciplinary orientation by linking theory and practice, which allows them to address and foster such matters of global importance as the Sustainable Development Goals (SDGs). Recently, Higher Education institutions have been overcoming global challenges by embedding challenge-based learning into the curriculum of study programs [2].

One of the defining characteristics of the 21st century is constant volatility and the various changes related to adapting to such instability in all walks of life, both on the personal level and the societal level. Higher Education, which is not an exception, has the primary role of helping students to take on challenges and to find solutions for them. Newly emerging societal challenges require new competencies and skills in order to address them and reduce their potential negative impact. To address this, Higher Education, in the last half of the 20th century, shifted towards various active student-centered learning methods, such as problem-, project-, design-, and, most recently, challenge-based learning, to name but a few [3–6].

In the available CBL literature, the types of challenges have been described by many researchers based on their extent. They are categorized as mini, nano, standard, and strategic challenges. The concept of a challenge could be defined as a question that turns into a call for action. Some authors define a challenge as a situation or activity that creates a sense of urgency and superior action and enables individuals to find sustainable and innovative solutions [7]. Promising ideas have been developed by researchers in terms of challenge-based education (CBE). The fundamental goal of challenge-based education is the construction of a learning process based on real-life situations [8,9] that makes a difference and proposes a deep, engaging, meaningful, and purposeful process [10]. Challenge-based education is usually seen as a branch of problem-based learning; however, it also has some unique characteristics compared with other similar student-centered learning methods [10]. Challenge-based education enables students to master different tools, technologies, and techniques as well as to become actively involved in taking actions. Validation of challenge-based education helps students to gain 21st century skills (e.g., critical thinking and problem solving, creativity and innovation, different literacies, flexibility and adaptability, communication and collaboration [11]) and develop a framework for life-long learning. Therefore, "[c]hallenge-based learning raises the level of ambition of engineering education to go beyond the technical systems domain into the socio-technical system domain" [10]. Due to the increasing numbers of more complex societal problems and the innovative spirit of Higher Education, it might be suggested that challenge-based education is a plausible way to move forward. However, existing research on challenge-based learning [11–13] allows us to infer that, in the context of Higher Education, institutions might be rather conservative and sometimes pay no or little attention to the Sustainable Development Goals.

Researchers emphasize the interactive nature of the CBE process, which provides an opportunity for students to create solutions in a real environment and develop professional skills and competencies [14]. Other previous studies on CBL reveal that the implementation of this method leads to student satisfaction, a good level of motivation due to the solving of real-life challenges, a better rapport between teachers and students, and an overall improvement in the learning process [15]. It has been shown that compared with traditional learning, in CBL students achieve better learning outcomes [14,16]. In general, according to recent studies, introducing CBL into engineering education has been proven to enhance and develop both disciplinary skills, such as being able to apply theory and technical skills in practice, and transversal skills, such as teamwork, communication, ethics, critical thinking, creativity, global awareness, information seeking, and life-long learning skills [13,17]. Some authors also stress that, in CBL, gaining the aforementioned skills and competencies takes place in a nonlinear manner, meaning that students develop them at different points of the course, but it is rather individual to each student [18]. This suggests that students might form diverse learning pathways, which calls for a more comprehensive description of an implementation that focuses on the design process and the emergence of students' learning pathways.

To explore this latter point more deeply and shed light upon it, the rest of the paper is structured as follows. The remainder of Section 1 elaborates on sustainable development in Higher Education and how it can be taught through CBL. Section 2 presents the methodology. Section 3 describes the results. Section 4 provides a discussion of the results. Section 5 draws a conclusion.

1.1. Relevance of Sustainable Development Goals in Higher Education

Over the years, the most industrialized economies have implemented different strategies that have resulted in lower emission levels for the majority of pollutants, more equality, more accessible education, etc. However, societies around the world are still struggling with climate change, pollution, and other challenges. For example, the global population continues to rise, and so does the number of people in large crowded cities. All of this has resulted in, for instance, issues with urban air quality, not only because of the rise in pollutant concentrations in many locations, but also because people are more exposed to contaminants as they move within or between the different areas. Certain sectors of society, including international organizations, associations, non-governmental organizations, and national governments, are concerned about the state of the planet and are taking steps to address the 17 Sustainable Development Goals set by the United Nations with the aim of addressing global issues, including poverty, well-being, innovation, the preservation of resources, and making cities and human settlements inclusive, safe, resilient, and sustainable. Such a goal is inseparable from technological advancement and the rapidly increasing need for more innovative solutions in multiple areas, applying state-of-the-art tools and methods to ensure a visible and measurable impact on the well-being of society as a whole. Therefore, multidisciplinary and flexible professionals capable of ethically solving relevant problems in local and global contexts are needed in 21st century society. It is not sufficient to merely possess knowledge and skills; one must also be able to apply them creatively to real-life situations within a defined, yet often rapidly changing environment. In order to solve social problems and raise living standards, these professionals must change current paradigms [13]. For these reasons, the SDG agenda calls for global collaboration at all levels between countries and stakeholders, including a diverse range of actors such as multinational corporations, local governments, regional and international organizations, and civil society organizations, who must collaborate to achieve objectives and priorities [19]. In this regard, Higher Education institutions (HEIs) and research centers (RCs) should play an active and central role in promoting and participating in the achievement of these new goals.

Scientists [20] agree that there is an environmental crisis as a result of the complex interaction between people and the environment. Simply caring for the world is not enough to keep it from being tarnished, so a sustainable mindset and consciousness are necessary as "[w]e acquire an environmental commitment when we reach an environmental consciousness, a multidimensional concept, in which several dimensions can be identified" [4]:

1. Cognitive: the degree of information and knowledge about environmental issues. This dimension refers to ideas.
2. Affective: the perception of the environment; beliefs and feelings on environmental matters. This dimension refers to emotions.
3. Conative: the willingness to adopt pro-environmental behavior; expressing interest in or a predisposition to participating in activities and making improvements. This dimension refers to attitudes.
4. Active: carrying out environmentally responsible practices and behavior, both individual and collective, even in compromised situations. This dimension refers to behaviors.

Governments, the private sector, and civil society should all take responsibility for promoting SDGs and the above-mentioned sustainable consciousness through education. SDG implementation is a global undertaking that must be carried out at the local level as well, taking into account the environmental background and socioeconomic factors of each location. The Director-General of UNESCO, Ms. Irina Bokova, claims [21] that since education has a catalytic effect on individual well-being and the future of the world, a paradigm shift in how people think about the role of education in global development is needed, and education now, more than ever, has a duty to align with 21st century challenges and expectations and promote the principles and skills that will contribute to both sustainable and equitable development to ensure a peaceful coexistence.

Despite the encouragement and endeavors to address the SDGs in HEIs, doing so might be a challenge on its own. A review article [6] on problems and solutions related to Education for Sustainable Development (ESD) in Engineering education summarizes and names the main barriers to implementing ESD in engineering. They are as follows: the lack of policy in different countries; the shortage of experienced academic staff; policy trade-offs between the current curriculum and ESD; and the lack of a partnership between universities, society, and industry [6]. Regardless of that, one can notice, based on the existing research and recommendations, that HEIs are still trying to tackle such hurdles by innovating the content of their study programs and modules and the way that students learn and take control of their entire learning journey or pathway. A number of examples can be seen, for instance, on the website of the European Consortium of Innovative Universities (ECIU), which is one of the current leaders in implementing CBL in HEIs [22].

Sonetti et al. [23] provide recommendations for the implementation of several different SDGs. For example, to develop SDG 4, universities are recommended to offer courses for all of academia regarding sustainable behaviors and their social, economic, and environmental impacts; to develop DSG 13, universities are encouraged to use a prosumer strategy to profit from co-creation with students and professors to improve the university's environmental footprint in campus operations as well as in teaching, research, and public impact; and (iii) to develop SDG 17, universities are invited to collect single intentions from energy providers to lower renewable energy costs or from national governments for more flexible green purchases [23]. Leal Filho et al. [24] recommend the enrichment of the learning experience by aligning curricula and research to SDGs, the testing and use of new contents, learning methods, and transformative approaches, the development of more applied research on the SDGs, and the engagement of students to commit to and act in support of the SDGs. Strachan et al. [25] recommend the embedding of research-based education for sustainable development. The authors [25] suggest the integration of the innovative pedagogy called 'vertically integrated projects', which gives students an opportunity to work with projects that are linked to outreach/community engagement and allows students to appreciate the impact that their discipline has in local and global social contexts.

Present and future engineers at HEIs, especially when teamed up with representatives of other fields, hold huge potential to achieve SDGs. Recently, many European universities have developed various initiatives to teach SDGs and, in particular, SDG 11, which is called "Sustainable Cities and Communities" [21]. This SDG relates to making cities and human settlements safe, resilient, and sustainable, which implies that people shall have a living environment with good conditions for health, a green environment without hazardous wastes, affordable transportation, and utilities supplied at a reasonable price. As the priorities of Agenda 2030 are social, economic, and environmental in nature, society needs competent engineers and other specialists with relevant theoretical knowledge and skills in achieving SDGs. SDG 11 is a viable choice for engineering education in order to produce professionals with the necessary competence in all of the aforementioned fields. The experts' views on incorporating SDG 11 into the engineering curriculum for schools are as follows [26]:

- the provision of required laboratories;
- exposure to societies and industries for the purpose of exchanging knowledge and skills; and
- the competence of academic staff with hands-on skills for the purpose of developing the required PO and CO matrices.

Once all of these aspects are covered, it is also important to combine them with a suitable innovative pedagogy to achieve the best outcome.

1.2. Addressing Sustainable Development Goals through Challenge-Based Learning

The United Nations [27] emphasize the role of education in developing responsible business leaders of tomorrow with a sense of sustainability and awareness. Education is one of the biggest opportunities for achieving that. Since education is an important topic in every community, teaching and learning methods should be tailored to the needs and realities of the environment in which they are created [28].

Society indeed puts high requirements on modern Higher Education institutions and the specialists that are prepared by them. To increase graduates' professional skills, all the information received by them has to be contextualized. As was mentioned above, soft skills should not be developed separately from engineering sciences (i.e., as individual modules); rather, they should be effectively integrated. Studies are becoming oriented towards competence-based qualifications from degree-focused qualifications. Some experts claim that the degree programs of a fixed curriculum will become less effective, while the greatest emphasis will be placed on the competencies developed. The increasing number of more complex local and global sustainable development problems and the cutting-edge innovations in HE make it evident that there is a need for a different type of pedagogy.

Challenge-based learning is a pedagogical approach that is being increasingly implemented in various disciplines [29,30]. The fundamental goal of challenge-based learning is the construction of a learning process based on real-life situations [9] that makes a difference and proposes a deep, engaging, meaningful, and purposeful learning process [7]. Challenge-based learning is currently one of the most suitable pedagogical methods for addressing SDGs. It provides:

- a multiple entry point strategy and varied and multiple possible solutions;
- a focus on universal challenges with local solutions;
- an authentic connection with multiple disciplines;
- an opportunity to develop 21st century skills;
- the purposeful use of Web 2.0 tools for organizing, collaborating, and publishing;
- the opportunity for students to do something rather than just learn about something;
- the documentation of the learning experience from challenge to solution; and
- 24/7 access to up-to-date technologies, tools, and resources so that students can do their work [31].

Scholars have found that as a pedagogical approach, challenge-based learning (CBL) deliberately engages students in a real-world problem that is important and connected to the context. CBL includes identifying a dilemma as well as implementing a solution [32].

Challenge-based learning is usually regarded as an evolution or an improvement of problem-based learning, but it certainly possesses some unique characteristics [10]. Challenge-based enables students to exploit the existing technology for their needs and take actions. Validation of Challenge-based learning shows that students gain 21st century skills and develop a framework for life-long learning. This is especially important in the context of Higher Education institutions that focus more on the so-called hard sciences, because "[c]hallenge-based learning raises the level of ambition of engineering education to go beyond the technical systems domain into the socio-technical systems domain" [10]. This proposes the idea that challenge-based learning could help universities, especially technical ones, to combine hard and soft skills so that their students obtain them simultaneously while they are working on a problem that is real and natural [9].

Similarly to many other scholars, the authors of [33] interpret challenge-based learning as a learner-centered approach to learning. In such a learning approach, learners work together in active and authentic learning environments to tackle the complex challenges of the 21st century world. As the authors of [6] also note, previous research reveals that CBL strengthens learners' collaboration, creativity, problem-solving, critical thinking, communication, and other skills critical to future decision-making, which, as one might argue, are essential to addressing SDGs [33].

CBL is particularly suitable to helping learners address SDGs because of its core principles and features. As the authors of a study on CBL [34] point out, CBL has nine key elements:

1. involvement of stakeholders (e.g., companies, start-ups, municipalities, etc.);
2. real challenges posed by stakeholders;
3. iterative application of innovation development methods;
4. teamwork in interdisciplinary and interdisciplinary groups of students;
5. effective verbal communication;
6. conscious competition between teams and independent evaluation of the results achieved;
7. practical activities, study visits, and other experiences that supplement the knowledge gained during lectures;
8. business model development and market analysis; and
9. a focus on the value creation process and the development of entrepreneurial skills.

While bearing significant advantages and offering numerous opportunities for improving the educational process and learning outcomes, CBL's implementation does face challenges that have to be addressed and prepared for in advance. It has been reported that, in some cases, students struggle to find technical solutions to given challenges. Even though autonomous learning is being promoted, students lack motivation and prefer a learning method that has been suggested and devised by the module's professor [26]. Professors have also expressed concerns that CBL might require more resources at both the instrumental level and the organizational level [27]. Other available CBL research also indicates that there is reluctance on the part of students to become more involved in and form a collaborative attitude towards this novel way of learning [14], which is undoubtedly a complex learning system.

Challenge-based learning starts with challenge identification and description. The concept of a challenge is defined differently by many researchers. It has been suggested that a challenge can be defined as a question that turns into a call for action [7]. It can also be seen as, for instance, a situation or activity that creates a sense of urgency that is followed by superior actions, consequently enabling one to find sustainable and innovative solutions. Challenges can be evaluated according to their significance as well as their spatial and temporal dimensions; however, the most important aspect of a challenge is that students and teachers work together to solve practical real-world problems [35].

In terms of the latter, CBL is similar to other active learning methods. However, as Malmqvist et al. [10] explain, "[c]hallenge-based education can be seen as an evolution from problem-based learning, but one that brings forward some unique characteristics such as a starting point in large open-ended problems, a value-driven approach to problem formulation and decision-making, training of self-awareness and self-leadership in combination with teamwork in projects that require addressing engineering problem-solving, societal concerns, and an entrepreneurial mindset and working method" [10] (p. 10). In addition, challenge-based learning has a specific structure, which consists of three main steps, namely engage, investigate, and act [31]. These three steps consist of the following sub-activities:

- Engage: Big Idea; Essential Questions; the Challenge
- Investigate: Guiding Questions; Guiding Activities and Resources; Analysis
- Act: Solution; Implementation; Evaluation and Publishing

The engagement phase begins with the presentation of a "global idea", for example, "sustainable cities and communities" (SDG 11). Students are invited to ask a series of questions to refine their ideas and decide in which specific direction their solution will be developed. At this stage, it is very important to define and work on an idea that would benefit society. Moreover, at this stage, students, by choosing the concrete idea to work on, are beginning to construct and shape their learning pathway.

During the investigation phase, students delve into a concrete idea and ask additional questions that help to identify what additional knowledge is needed to address the challenge. This phase identifies activities and resources to help address the challenge successfully. After the systematization of the collected information, the obtained data are analyzed, which is performed with the help of mentors and by using various tools, including hardware and software.

Using the collected data, students begin to look for a possible solution to the challenge during the acting phase. The solution is sought by producing prototypes, experimenting, consulting student teams internally, and corresponding with business, society, and so on. Once a suitable solution has been found, an action plan is drawn up for its implementation, so drawings, detailed descriptions, selected materials, and indicators are prepared that will allow for the benefits of the solution's implementation to be assessed. Once the solution is deemed to have been properly prepared, it is implemented. The outcome and success of its implementation are then analyzed, and the impact on society is identified. After that, students are encouraged to present their results not only within the framework of the study module but also beyond that, especially through social media, student conferences, and other public events and/or spaces.

1.3. Challenge-Based Learning Design and Learning Pathways

In the most general sense, learning pathways can be defined as various learning experiences, including courses and academic programs, that lead to graduation. Alternatively, learning pathways have also been referred to as learning journeys, niches, and trajectories [36]. In addition to formal learning in the academic environment, learning may also take place informally (e.g., at the workplace) [36]. However, this way, it is more sporadic and is not necessarily supported by an expert mentor.

Advancements in educational technologies, with the support of AI, learning analytics, etc., allow for the automatized and adaptive development of learning pathways [37]. As suggested by Finland's Omnia [38], learning pathways and their personalization offer a number of benefits, including but not limited to more flexibility, improvements in the quality of studies, meaningful learning, relevance to professional life, authentic tasks, support from stakeholders in providing real-life problem-solving and competence application contexts, and more overall guidance and support to students [38].

Learning pathways are described as having the following three features: "(1) they are taken up in relation to identities, and have relational, affective, and motivational components; (2) they are made up of sets of cultural practices and routines, socially constructed by the self and others, and build up over multiple instances and protracted time periods; and (3) they include elements of privilege and marginalization that occur in relation to structural constraints and supports which are experiences by learners in their families, peer relations, and institutions such as schools" [39]. Another important characteristic of learning pathways is that they "are numerous, multifaceted, and inherently unique to each individual" [36], especially when new student-centered and student-driven pedagogies, such as CBL, are implemented.

The Sustainable Development Goals (SDGs), agreed upon by the United Nations in 2015, are receiving a significant amount of attention in engineering policy and practice. However, it is unclear whether current and future engineering graduates will be equipped to contribute significantly to the achievement of these goals and deliver sustainable engineering solutions [40]. Nevertheless, one might argue that the learning pathways that emerge based on the framework of the CBL process embedded into different study modules might enable and empower students. It is important to note that the implementability of the Sustainable Development Goals (SDGs) depends on effective Project Planning, Development, and Management (PPD&M), extensive possibilities for open learning modules that are made available to wider audiences, and the collaboration of students worldwide via distance education. The redesigned content emphasizes the ability to interrelate, through appropriate toolsets, challenges, priorities, themes, and sectors in the project development management domain [40].

When teachers, who are usually also the designers of their study modules, are planning to implement CBL to allow students to follow different and higher-quality learning pathways while working on various SDG solutions, a number of important aspects need to be taken into account. However, it is important to focus on curricula in terms of SDG coverage and new skill sets. Some authors recommend the following steps for embedding Sustainable Development Goals (SDGs) within engineering degree programs: (1) identify exemplary program content and learning outcomes for sustainability and work with lecturers to embed these in curricula; (2) engage with lecturers, other educators, and teaching and learning centers on the development of learning outcomes and highlight the importance of sustainability; (3) work with industry and professional/accreditation organizations to develop future-ready graduates; (4) further focus on education that involves cross-disciplinary collaboration, such as social sciences and engineering; (5) further incorporate sustainable development into life-long learning, reskilling, and upskilling institutions and courses; and (6) further incorporate sustainable development into primary and secondary education systems [41].

2. Methods

2.1. Methods, Design, and Settings

To address the research questions related to students' learning pathways in an SDG-11- and CBL-focused study module, a qualitative research method, more precisely, a case study, was selected. The case study was selected in regard to the research questions in order to control research and actual behavioral elements and to focus on contemporary events. A case study can be defined as an empirical study that aims to investigate a contemporary phenomenon in its real context, especially when the boundaries between the phenomenon and the context are not clearly visible [42]. It has also been suggested that a case study is a good research strategy when research questions are formulated using the question words 'how' and 'why' [42]. Accordingly, the case study was chosen to analyze how challenge-based learning was adopted in a Master's degree program for engineering students and to determine the main aspects of combining SDG 11 and challenge-based learning. To collect relevant qualitative and quantitative data, the research was conducted in the context of studies within the engineering discipline. The research focuses on the approach to the design of study modules and learning pathways and the implementation of Challenge-based learning and SDGs in practice.

2.2. Sample

The study module "Artificial intelligence and design making" was observed and case study data were collected during the 2020–2021 Fall semester. All data were collected by using the University's study system (open.ktu.lt), which students who enroll in the courses are aware of. In the scope of the study, 30 students, out of whom 28 were males and 2 were females, were enrolled in the course together with the three teachers of the module.

2.3. Ethical Considerations

Both the students and the module's teacher were aware of the ongoing observation of the module's progress. No personal data were collected. When providing examples of students' work and their learning pathways, all details were anonymized even though their solutions to challenges have been publicly presented a number of times and there are various publicly available presentations (including videos on YouTube) that showcase their work, attitudes, achievements, etc.

2.4. Data Collection

The research data were collected during the challenge-based learning implementation process by the module's teacher, whose reflections and account of the process are also important sources of data used in the paper. During the implementation, the module's teachers administered questionnaires to students on the progress of their challenge solutions, perceived benefits, gained competencies, and other relevant details needed to adjust the working progress if needed. All the collected data were anonymized by one of the course teachers by applying statistical analysis methods.

2.5. Instruments Used

The theoretical framework was built to be related to the learning process. It started with choosing the challenge related to SDG 11, which was called "making communities and urban environments inclusive, safe, as well as resilient to disasters and adaptable to challenges like climate change". In the next step of the challenge-based learning process, students were able to select their learning pathway to solve the challenge and to develop skills and knowledge to support their learning pathway. The case study is based on the reflections, feedback, and assessments of the module's teachers, the students, and the challenge owners.

2.6. Data Analysis

The data used were anonymized and analyzed through the lens of constructivism to design the support and evaluation processes. The framework of the research was based on three main foci, namely the challenge-based learning process, solving SDG 11 problems together with challenge owners and stakeholders, and emerging learning pathways.

3. Results

The present paper describes the case study through the process of emerging learning pathways within a CBL- and SDG-11-focused study module. The overall process is portrayed in Figure 1. As one might see, students, supported by the course teacher (1), begin the journey by choosing the challenge related to the SDG 11 topic and (2) applying the discipline and choosing the module and its topics of advanced knowledge and applications with the support of (3) the challenge provider and the discipline teacher. By going through steps (4) and (5), they (6) obtain a certificate for the discipline and the transversal skills related to the challenge solution's implementation (see Figure 1). A more detailed account of each implementation stage and the main milestones in students' learning pathway is given in the following subsections.

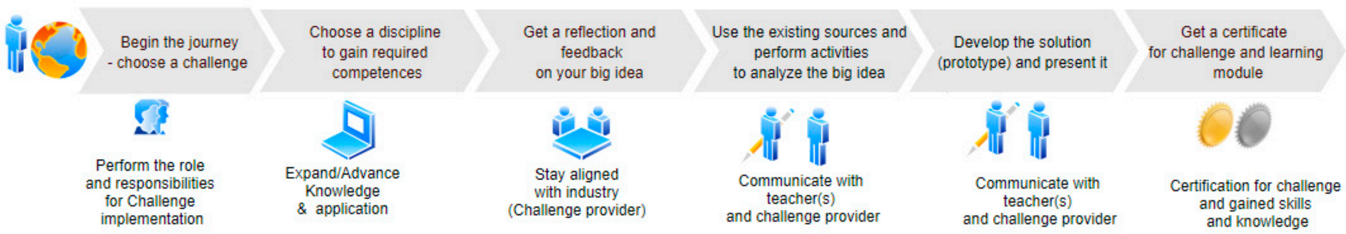


Figure 1. Learner's pathway by implementing solutions to challenges and obtaining skills and knowledge from the study module.

When it comes to the context of the study, it was heavily shaped by the selected challenge and the related big idea, namely "Efficient management of resources in Kaunas City". This challenge, together with the CBL methodology, was embedded into the Master's degree study module called "Artificial intelligence and decision-making".

The goal of the challenge was to enable the transition to a circular economy in Kaunas City, where a much stronger focus is needed on waste prevention, re-use, repair, and recycling. Many cities, together with the government, companies, communities, and citizens, have made great strides towards becoming more sustainable. Kaunas City has made great strides towards becoming more sustainable; however, it still needs to point citizens in the right direction. The main challenges are related to the availability and reliability of mapping data and stakeholders' engagement in the resource management context, as well as the actual redirection and exchange of material flows between stakeholders. The expected impacts involved identified opportunities to use the economic potential of the existing material flows. Supporting and enabling stakeholders to exploit these opportunities may help speed up the city's transition to a circular economy in terms of resource efficiency. Urban resource management started with understanding the city's metabolism—this means better identifying and understanding the material stocks and flows within the city. From an educational perspective, the main task was to integrate the CBL methodology and challenge-related tasks into the subject, which was oriented around teaching students to create smart decision-making systems by using different machine learning algorithms. Moreover, it was necessary to create synergy between students from different disciplines and to ensure mutual benefits for challenge owners and challenge solvers (students).

Ten teams consisting of three to six students were formed. The majority of students were from the IT area, several students were from mathematics, automatics, and electronics, and a few students were from social sciences. Only a few students were familiar with similar active learning methodologies, such as problem-based learning (PBL). In addition, given that there were 10 teams, it appeared to be reasonable to split this broad challenge into smaller and different sub-tasks, including only one condition that all suggestions must be related to the provided challenge. Such a decision was plausible considering the fact that very interesting, innovative, and fresh ideas were suggested by the students, such as: (i) a data-centric analysis of crime rates in Kaunas; (ii) an air pollution monitoring system; (iii) a socio-civic garbage reduction system; (iv) an automatic image-based garbage sorting system; (v) intelligent distribution of air pollution stations in Kaunas City; and (vi) smart garbage containers.

On the way to developing the aforementioned innovative ideas, students gained a number of different competencies and skills. As was mentioned in the Methods section, students were asked about the perceived benefits of learning through CBL. As can be seen in Figure 2, students identified a number of different skills and competencies that they improved while working on their SDG-11-focused challenge solutions.

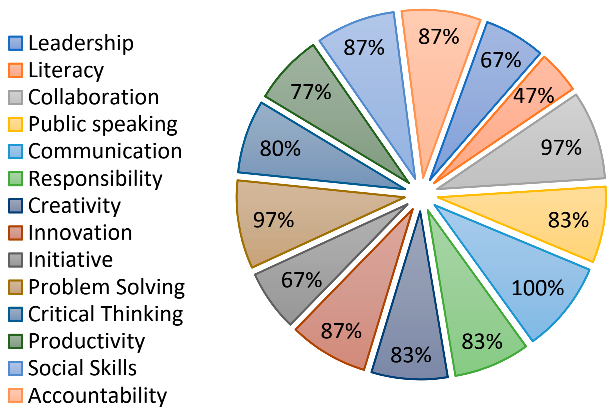


Figure 2. Competencies and skills improved by students in the SDG-11-focused module.

The challenge-based learning cycle was run for 13 weeks. All activities and achieved results are described in the following subsections.

3.1. CBL Engagement Stage (Weeks 1–3)

The first stage of CBL implementation took three weeks. During this time, students began shaping their learning pathways by narrowing down the challenge that they wanted to address.

Week 1: The first task was to introduce the challenge-based learning approach and give an explanation of how the challenge(s) would be addressed during the semester

(13 weeks). The module's teachers put the students into groups of up to five to work on the task.

Week 2: Together with the course teachers, students explored the possibilities of creating AI-based sustainable solutions, which could be valuable for the city of Kaunas and fully completed in a relatively short time. Examples from foreign countries were observed and discussed. As for SDG 11, sustainable transport, the environmental impact of cities (waste management, air quality, etc.), and safe and green areas were the most attractive to the students.

Week 3: In the third week, it was important to identify the guiding questions and activities that would help to answer the key questions and create innovative and sustainable solutions for Kaunas City. It was also important to learn how the questions could be categorized and prioritized in order to create the learning pathways. Students formulated essential questions and provided the initial versions of questions. Examples of the formulated questions are provided in Tables 1–3. During the interactive lectures, the challenge and the overlap of its goals with the study module's goals were discussed and all findings were recorded.

Table 1. Smart parking system: essential questions.

CBL-Related Questions	Technical Questions	Subject-Related Questions
1. Is it necessary to involve students from different study programs in each group? 2. What should be the completion point of the project according to the CBL methodology? 3. Should we integrate all CBL methodology steps for IT solutions? Should we allow some of them to be skipped?	1. How many cameras are implemented in Kaunas City? 2. Are these cameras static or can they rotate? 3. Is it possible to obtain information from these cameras? Where do we apply for data? 4. Do we need to evaluate only free parking places or paid parking as well?	1. Are there any open-source data sets of parking video recordings? 2. Is it possible to use a pre-trained convolutional neural network (CNN) [43,44] model for the problem? 3. How should the systems behave in extreme weather conditions (e.g., it is impossible to identify parking lines because of snow)? 4. Do we need to evaluate how much space is needed for particular vehicles (e.g., SUVs, motorcycles)? 5. How should the decision-making system behave in the absence of parking signs? 6. Do we have to consider road signs or road markings? 7. Should the system calculate the number of free parking spaces or provide empty space measurements as well?

Table 2. Intelligent waste prediction system: essential questions.

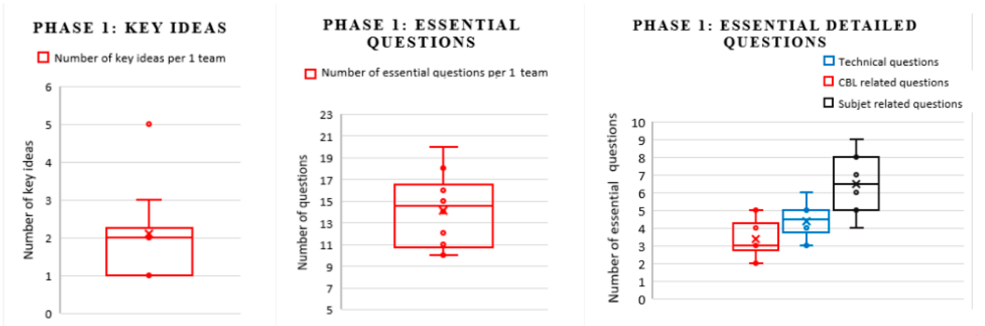
CBL-Related Questions	Technical Questions	Subject-Related Questions
1. What is the difference between PBL and CBL? 2. Must the data be taken from Kaunas City only? 3. Do we need to create a fully fledged product or is it enough to provide the prototype? 4. Do we have to calculate the price of the prototype or the solution? A single purchase price in bulk?	1. What types of sensors should be integrated (ultrasonic, weight-based, etc.)? 2. How do we ensure the safety of integrated devices so that they are not misappropriated or damaged by anyone? 3. Do we need to provide the optimal route as well, or the AI prediction system only?	1. What are the functional and non-functional requirements for the decision-making system? 2. How do we determine the best data collection frequency (i.e., ~30 min)? 3. What will be the format of the collected data (timestamp or container fill level)? 4. What is the best machine learning algorithm for the prediction problem? 5. What is the period for prediction?

Table 3. Automatic pothole detection system: essential questions.

CBL-Related Questions	Technical Questions	Subject-Related Questions
1. Do all team members work individually or do they have to contribute to all activities? 2. What should be the completion point of the project? Do we have to create a fully fledged product or is it enough to provide the prototype? 3. How different is the CBL-based realization sequence from regular IT projects (systems)?	1. Is it possible to ensure sufficient video streaming speed and quality using mobile phone or dash camera devices? 2. Are there any specific requirements for video recording devices? 3. What is the maximum speed of the vehicle required to detect the pothole? 4. What kind of information should be recorded and sent to the server?	1. What is the appropriate frequency of image processing? 2. Should automatically recognized potholes be confirmed by drivers? 3. Are there any open-source data sets of the pothole images required to train the CNN? 4. Which CNN architecture should be implemented? 5. What kinds of model metrics should be evaluated? 6. Could the weather (e.g., snow, rain) or poor lighting impact the accuracy of the model?

According to the module's teachers, in terms of CBL activities, the most challenging was the first engagement level, at which big ideas and essential questions related to the challenge topic are formulated and discussed.

The quantitative parameters of engagement-level outcomes were measured in the course and are provided below (see Figure 2). It was observed that, on average, each group provided 2.1 key ideas and 14.1 essential questions. It was noticed that the essential questions could be grouped into the following three target groups: CBL-methodology-related questions, technical questions, and subject-related questions. The size proportion of each question group is provided in the box plots shown in Figure 3c.



(**a**) (**b**) (**c**)

Figure 3. Quantitative parameters of CBL engagement level outcomes: (**a**) the number of key ideas in Phase 1, (**b**) the number of essential questions in Phase 1, and (**c**) the number and types of detailed essential questions in Phase 1.

3.2. CBL Investigation Stage (Weeks 4–8)

The most important, as well as the most time- and effort-consuming, stage of the entire study module was the investigation stage, during which students truly developed their learning pathways both individually and as a group.

Weeks 4–5: The main goal was to provide access to information and resources that are relevant to students' selected challenges. Students were supplied with reliable resources, including websites, videos, databases, contact information of representatives of the Kaunas City municipality, and other content that might help to provide answers to the questions. It was noted that the resources most commonly used by the students were open-source databases, consultations with the challenge owner, different websites, and AI/IT software.

Week 6: Based on the gathered data, insights and remarks were provided. It is important to note that two of the groups encountered challenges with data collection (quality issues with the data on air pollution in Kaunas City, video recordings of some parking areas); therefore, alternative solutions were discussed.

Weeks 7–8: According to the results of all findings and reflections, the primary conception of the challenge solution was developed by identifying potential AI methods (ML algorithms), realization tools (programming languages, platforms, etc.), solution architectures, and so on.

Most of the essential questions (the average value was 6.5) were related to the subject; more specifically, solution realization details, machine learning algorithms, and artificial intelligence techniques. The essential questions for the big idea, which was narrowed by the groups of students into three challenges, are provided in Tables 1–3.

The first example of a challenge solution is a smart parking system. Finding a free space to park a car in some areas in Kaunas (e.g., the city center, old town, etc.) can be a really frustrating task for any driver. The purpose of this challenge was to create an AI free parking system that navigates drivers all the way to an empty parking spot and maximizes the chance of finding a free parking spot quickly.

During the challenge-solving phase, students reached a few milestones. For the presented solution, students calculated that a parking accuracy between 81 and 88% could be reached depending on the weather and the selected threshold. The processing time of a video frame is up to 500 ms depending on the frame quality. The prototype of the proposed solution can be seen in Figure 4.

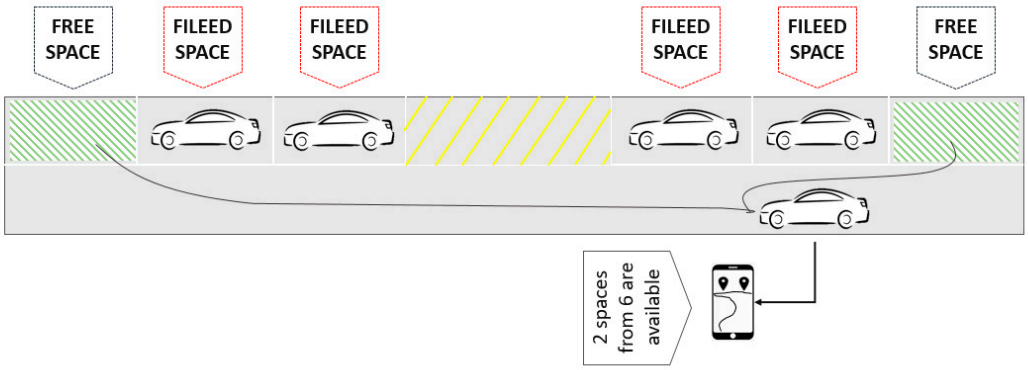


Figure 4. Graphical scheme of the smart parking system solution.

The second example of a challenge solution is an intelligent waste prediction system. Efficient waste management is an important issue for growing urban areas. Overfilled trash cans can lead to public dissatisfaction and complaints, while half-empty cans will lead to higher costs for waste management agencies. Thus, as a solution to this challenge, students presented a garbage prediction system. Students identified the components of the smart bin prototype, namely a Raspberry Pi Zero microcomputer, a NEO-6M GPS module, an HC-SR04 ultrasonic sensor, and a microSD card reader. The biggest challenges of the proposed solution were argued to be the difficult mounting process, risks of detachment, and assurance of continuous monitoring.

The graphical representation of the proposed challenge solution can be seen in Figure 5 below.

The third example of a challenge solution is an automatic pothole detection system. The main goal of the system was to detect potholes on the road using image recognition and machine learning and mark their approximate locations on a map. The proposed system should help to organize a more efficient road construction and maintenance schedule, based on information provided by civilians (drivers). Students identified that the main problem was that potholes in Kaunas City can remain unfixed for extended periods of time, even if local authorities are notified about them. They settled on the goal of a system to simplify the job of marking potholes, which would do so automatically and store the data in a database. Marked potholes were displayed on a map, which helps to effectively plan road repairs. Accumulated data could be utilized to assess the long-term quality of roads.

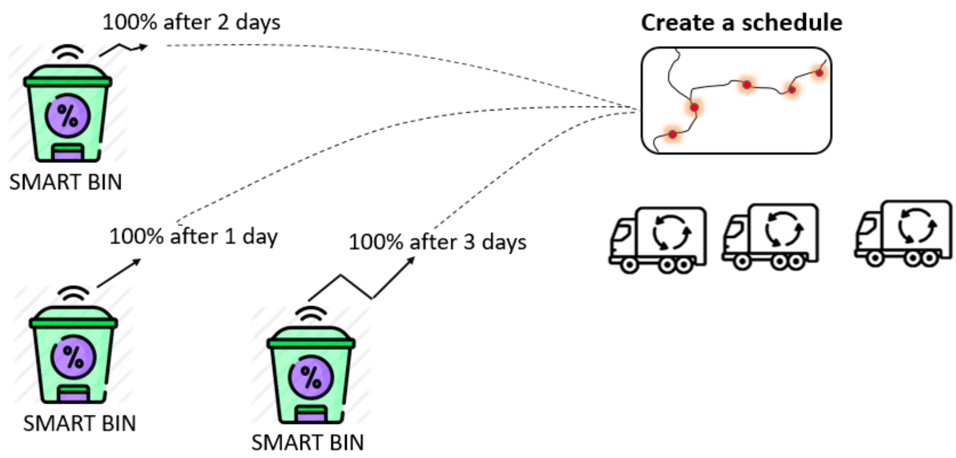


Figure 5. Graphical scheme of the intelligent waste prediction system.

The pothole detection task was considered to be a computer vision object; therefore, deep learning techniques were implemented. The convolutional neural network architecture YOLO v4 [45] was chosen because it yields highly accurate results in a reasonable period of time and is available in an online mode.

This data set contained 665 photos with annotation files representing the potholes on the road. Using k-fold cross validation (where k is equal to 7), the models achieved a mean Average Precision (mAP) of 86%. Finally, the trained model was redesigned from YOLO v4 to a TensorFlow Lite model to facilitate the model's integration into a mobile application or other external device. The model is graphically represented in Figure 6.

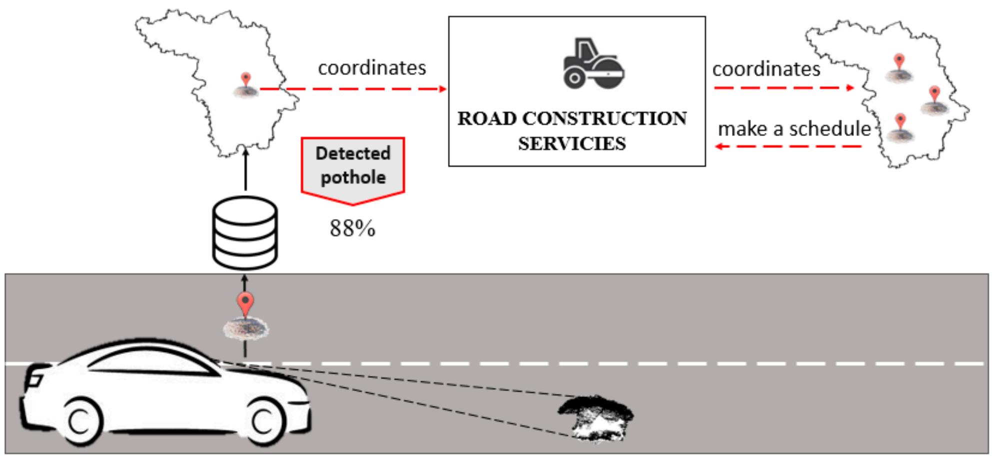


Figure 6. Graphical scheme of the automatic pothole detection system.

3.3. CBL Action Stage (Weeks 9–13)

The solution of the challenge belonging to SDG 11 was finalized and presented during the final weeks of the study module.

Week 9: In the CBL "Act" stage, the first step was to approve the final concept for solving the challenge and develop a prototype. Together with the separate teams, a plan for the solution's implementation was developed.

Weeks 10–12: The challenge solution concept was approved within two weeks through group discussions and consultations with the subject coordinator, the challenge owner, potential users, and other relevant stakeholders. A prototype was developed

(Python language platforms were preferred) using the practical knowledge and skills acquired during laboratory work, which focused on implementing various machine learning algorithms.

Week 13: In the end, the solution was presented in a final report and an oral presentation with all material collected throughout the challenge (text documents, video files, technical specifications, images, etc). Final solutions were presented to the representatives of the Kaunas City municipality, academia, and other stakeholders.

4. Discussion

The findings of this study indicate that challenge-based learning can be an effective method to raise students' awareness of SDGs. Due to the complex nature of the SDGs, students can effectively study with their own pathway the solution to a challenge, while at the same time integrating subject-specific skills and knowledge.

As a takeaway from this study, the most important aspects of CBL and SDGs in Engineering Studies are presented in Figure 7.

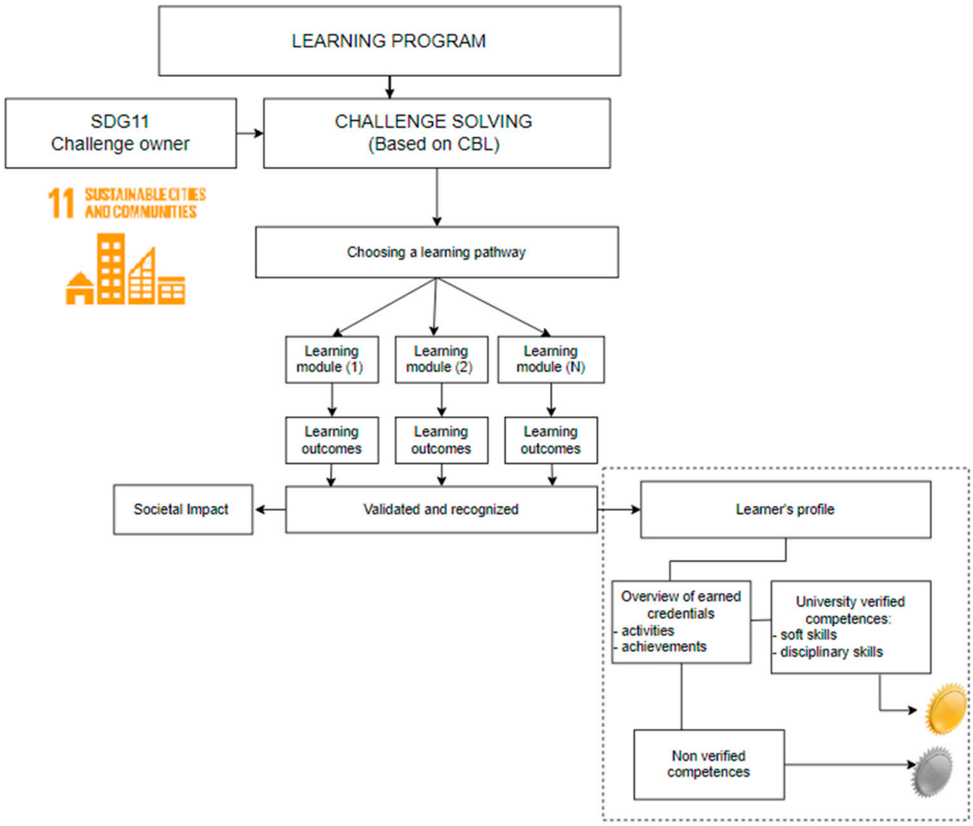


Figure 7. The methodological framework of CBL and SDG integration into learning modules.

An understanding of challenge-based learning at the study module level is considered to be an important initial stage. The teacher has to rethink and redesign the study process. Moreover, at this stage, there is a need to combine the study module's learning outcomes with a challenge. Secondly, the challenge owner plays a key role in the challenge's creation and description. The teacher and the challenge provider need to work closely together (see Figure 8). The teacher has to refine the expectations of the challenge provider in order to be able to advise the students in the context of solving the challenge. The user's roles can be seen in Figure 8.

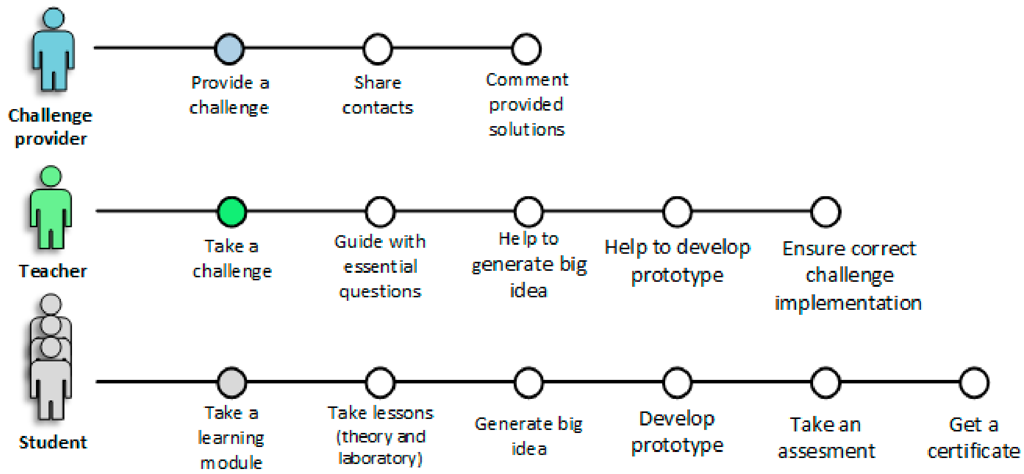


Figure 8. Stakeholders' roles and students' learning pathway.

Students (users) have freedom in regard to the study module's learning outcomes and the CBL methodology to form their own team's learning pathways. When students feel that they have the right to choose, they are more motivated to solve a challenge and provide a solution, which is consistent with the findings of the previous CBL studies mentioned earlier in the present paper. This can clearly be seen from the CBL Engagement stage (Weeks 1–3), which is related to the big idea and challenge. Students are invited to search for subject-related (in the described case, AI) problems for sustainable living or other subject-related problems associated with SDG 11. Therefore, students start their own learning path in search of sustainable problems relevant to the area, for the solution of which subject-related knowledge and skills can be integrated. During the CBL Investigation stage (Weeks 4–8), students recognize the power of the data because the accuracy of the challenge solution strongly depends on the data set. Whereas the decisions are based on real problems in the local environment, the data have to be obtained from the relevant authorities. Students learn how to formulate correct questions and to communicate with officials when asking for the data that they need. Not all experiences in data gathering will be successful; however, it is considered to be a good experience and students can learn from mistakes, which creates room for growth and the development of valuable social skills. In the CBL Action stage (Weeks 9–13), students present a challenge solution to the owner of the challenge and different stakeholders (not only the academic community). Students learn how to sell their idea, argue for the chosen solution path, and answer a variety of questions. Moreover, at this stage, students have to demonstrate the societal impact of the presented challenge solution based on evidence. During the entire challenge-based learning process, they have to envision and realize the impact of their solution on the SDG.

With a chosen challenge that shapes the learning pathway, students expand their skills and competencies outside of the study module. They learn how to deal with real environmental problems, include existing data sets, construct the solution to the challenge, and measure the societal impact of the proposed solution. The greatest value of the learning pathways lies not only in the detailed presentation of the solutions themselves, but also in the careful cost assessment, the detailed situation analysis, teamwork, etc. It shows that involving students in solving a challenge is valuable to students, academia, challenge providers, and society at large. That is particularly evident as some students, even after the successful completion of the module, continued to work on their SDG-11-related ideas. More precisely, one third of the proposed solutions are currently being developed further, and some students chose to incorporate the topics into their final degree projects. Another recorded additional benefit to the students was employment offers, which led to at least one of the foreign students obtaining a job.

5. Conclusions

The research presented in this paper used a case study methodology and sought to describe learners' pathways in a module focused on SDG 11 and CBL. The results show that the participants (i.e., students) generated sustainable solutions (potential business) ideas that aimed to resolve local, national, and global problems related to the SDG. Moreover, students received recommendations to continue working on their prototypes and to take them to further Technology Readiness Levels (TRLs) (e.g., TRL 5), which allow us to more clearly estimate and indicate the maturity of technologies during the acquisition phase of a program. These ideas may become real ventures that connect various actors and will continue to strengthen transversal skills such as teamwork and communication as well.

CBL, in connection with the priorities of the SDGs, is an innovative teaching methodology that engages students in engineering programs to resolve real-world challenges while applying the knowledge that they acquired during their professional training in terms of CBL activities. The challenges encountered by teachers and students were unlike the ones described earlier in the paper. The most challenging was the first phase of the CBL methodology's implementation, namely engagement, in which big ideas and essential questions related to the challenge topic are formulated and discussed.

With the chosen challenge and learning pathway, students expanded the scope of their skills and competencies outside of AI. They learned how to deal with real environmental problems, include existing data sets, construct the solution to the challenge, and measure the societal impact of a proposed solution.

Quantitative parameters of engagement-level outcomes were measured in the course and was observed that, on average, each group provided 2.1 key ideas and 14.1 essential questions, which is an inclusive result of the learning module.

A case analysis of the implementation of challenge-based learning in a Master's degree program for engineering students highlighted the main aspects of combining sustainable development goals and challenge-based learning. In response, using case study data drawn from the "Artificial intelligence" study module, we discussed different learning pathways that vary depending on students' engagement and SDG awareness and the instructional design.

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References

1. Martin, M.; Godonoga, A. *SDG 4-Policies for Flexible Learning Pathways in Higher Education: Taking Stock of Good Practices Internationally*; IIEPUNESCO: Working Papers; International Institute for Educational Planning: Paris, France, 2020. [CrossRef]
2. Lovren, V.O.; Maruna, M.; Stanarevic, S. Reflections on the learning objectives for sustainable development in the higher education curricula–three cases from the University of Belgrade. *Int. J. Sustain. High. Educ.* **2020**, *21*, 315–335. [CrossRef]
3. Castro, M.P.; Zermeno, M.G.G. Challenge Based Learning: Innovative Pedagogy for Sustainability through e-Learning in Higher Education. *Sustainability* **2020**, *12*, 4063. [CrossRef]
4. Del Cerro Velazquez, F.; Lozano Rivas, F. Education for Sustainable Development in STEM (Technical Drawing): Learning Approach and Method for SDG 11 in Classrooms. *Sustainability* **2020**, *12*, 2706. [CrossRef]
5. UNESCO Official Website. SDG Resources for Educators—Sustainable Cities and Communities. Available online: https://en.unesco.org/themes/education/sdgs/material/11 (accessed on 21 May 2021).
6. Shahidul, M.I. Engineering education for achieving sustainable development goals by 2030: Revealing the paths for challenging climate change and Covid 19. *Sci. Int.* **2020**, *32*, 403–410.
7. Nichols, M.; Cator, K.; Torres, M. *Challenge Based Learner User Guide*; Digital Promise: Redwood City, CA, USA, 2016. Available online: https://www.challengebasedlearning.org/wp-content/uploads/2019/02/CBL_Guide2016.pdf (accessed on 14 July 2021).
8. Johnson, L.F.; Smith, R.S.; Smythe, J.T.; Varon, R.K. *Challenge-Based Learning: An. Approach for Our Time*; The New Media Consortium: Austin, TX, USA, 2009; ISBN 978-0-9765-0874-8.
9. Johnson, L.; Brown, S. *Challenge Based Learning: The Report from the Implementation Project*; The New Media Consortium: Austin, TX, USA, 2011; pp. 1–36, ISBN 978-0-9846-6010-0.
10. Malmqvist, J.; Rådberg, K.K.; Lundqvist, U. Comparative analysis of challenge-based learning experiences. In Proceedings of the 11th International Conference (CDIO 2015), Chengdu, China, 8–11 June 2015. [CrossRef]
11. Voogt, J.; Roblin, N.P. *21st Century Skills: Discussion Paper*; University of Twente: Enschede, The Netherlands, 2010; 56p.
12. Cirenza, C.F.; Diller, T.E.; Williams, C.B. Assessing Effects of Challenge-Based Instruction on Conceptual Understanding in Heat Transfer. In Proceedings of the 122nd ASEE Annual Conference & Exposition (2015), Seattle, WA, USA, 14–17 June 2015; pp. 26.239.1–26.239.13.
13. Félix-Herrán, L.C.; Rendon-Nava, A.E.; Jalil, J.M.N. Challenge-based learning: An I-semester for experiential learning in Mechatronics Engineering. *Int. J. Interact. Des. Manuf.* **2019**, *13*, 1367–1383. [CrossRef]
14. López-Fernández, D.; Sánchez, P.S.; Fernández, J.; Tinao, I.; Lapuerta, V. Challenge-Based Learning in Aerospace Engineering Education: The ESA Concurrent Engineering Challenge at the Technical University of Madrid. *Acta Astronaut.* **2020**, *171*, 369–377. [CrossRef]
15. Membrillo-Hernández, J.; Muñoz-Soto, R.B.; Rodríguez-Sánchez, Á.C.; Díaz-Quiñonez, J.A.; Villegas, P.V.; Castillo-Reyna, J.; Ramírez-Medrano, A. Student engagement outside the classroom: Analysis of a challenge-based learning strategy in biotechnology engineering. In Proceedings of the IEEE Global Engineering Education Conference (EDUCON 2019), Dubai, United Arab Emirates, 8–11 April 2019; pp. 617–621. [CrossRef]
16. Ortiz, O.O.; Franco, J.Á.P.; Garau, P.M.A.; Martín, R.H. Innovative mobile robot method: Improving the learning of programming languages in engineering degrees. *IEEE Trans. Educ.* **2016**, *60*, 143–148. [CrossRef]
17. Singh, A. A new approach to teaching biomechanics through active, adaptive, and experiential learning. *J. Biomech. Eng.* **2017**, *139*. [CrossRef]
18. Juárez, E.; Aldeco-Pérez, R.; Velázquez, J.M. Academic approach to transform organisations: One engineer at a time. *IET Softw.* **2020**, *14*, 106–114. [CrossRef]
19. Caiado, R.G.G.; Leal Filho, W.; Quelhas, O.L.G.; de Mattos Nascimento, D.L.; Ávila, L.V. A literature-based review on potentials and constraints in the implementation of the sustainable development goals. *J. Clean. Prod.* **2018**, *198*, 1276–1288. [CrossRef]
20. Steffen, W.; Persson, Å.; Deutsch, L.; Zalasiewicz, J.; Williams, M.; Richardson, K.; Crumley, C.; Crutzen, P.; Folke, C.; Gordon, L.; et al. The Anthropocene: From global change to planetary stewardship. *Ambio* **2011**, *40*, 739–761. [CrossRef]
21. BORGEN Magazine. Available online: https://www.borgenmagazine.com/unesco-irina-bokova/ (accessed on 30 June 2021).
22. The European Consortium of Innovative Universities (ECIU) Homepage. Available online: https://www.eciu.org/ (accessed on 28 June 2021).
23. Sonetti, G.; Brown, M.; Naboni, E. About the triggering of UN sustainable development goals and regenerative sustainability in higher education. *Sustainability* **2019**, *11*, 254. [CrossRef]
24. Leal Filho, W.; Shiel, C.; Paço, A.; Mifsud, M.; Ávila, L.V.; Brandli, L.L.; Molthan-Hill, P.; Pace, P.; Azeiteiro, U.M.; Ruiz Vargas, V.; et al. Sustainable development goals and sustainability teaching at universities: Falling behind or getting ahead of the pack? *J. Clean. Prod.* **2019**, *232*, 285–294. [CrossRef]
25. Strachan, S.M.; Marshall, S.; Murray, P.; Coyle, E.J.; Sonnenberg-Klein, J. Using Vertically Integrated Projects to embed research-based education for sustainable development in undergraduate curricula. *Int. J. Sustain. High. Educ.* **2019**, *20*, 1313–1328. [CrossRef]
26. Transforming Our World: The 2030 Agenda for Sustainable Development. Available online: https://sdgs.un.org/2030agenda (accessed on 28 June 2021).
27. Progress Report: Uniting Business in the Decade of Action. Available online: https://sdghub.com/project/progress-report-uniting-business-in-the-decade-of-action/ (accessed on 30 June 2021).

28. Conde, M.Á.; Sedano, F.J.R.; Fernández-Llamas, C.; Gonçalves, J.; Lima, J.; García-Peñalvo, F.J. RoboSTEAM project systematic mapping: Challenge based learning and robotics. In Proceedings of the IEEE Global Engineering Education Conference (EDUCON 2020), Porto, Portugal, 27–30 April 2020; pp. 214–221. [CrossRef]
29. Gallagher, S.E.; Savage, T. Challenge-based learning in higher education: An exploratory literature review. *Teach. High. Educ.* **2020**, 1–24. [CrossRef]
30. Leijon, M.; Gudmundsson, P.; Staaf, P.; Christersson, C. Challenge based learning in higher education—A systematic literature review. *Innov. Educ. Teach. Int.* **2021**, 1–10. [CrossRef]
31. Nichols, M.H.; Cator, K. *Challenge Based Learning White Paper*; Apple, Inc.: Cupertino, CA, USA, 2008. Available online: https://www.challengebasedlearning.org/wp-content/uploads/2019/03/CBL_Paper_2008.pdf (accessed on 14 July 2021).
32. Rodríguez-Chueca, J.; Molina-García, A.; García-Aranda, C.; Pérez, J.; Rodríguez, E. Understanding sustainability and the circular economy through flipped classroom and challenge-based learning: An innovative experience in engineering education in Spain. *Environ. Educ. Res.* **2020**, *26*, 238–252. [CrossRef]
33. Tang, A.C.; Chow, M.C. To evaluate the effect of challenge-based learning on the approaches to learning of Chinese nursing students: A quasi-experimental study. *Nurse Educ. Today* **2020**, *85*, 104293. [CrossRef] [PubMed]
34. Martínez, M.; Crusat, X. Work in progress: The innovation journey: A challenge-based learning methodology that introduces innovation and entrepreneurship in engineering through competition and real-life challenges. In Proceedings of the IEEE Global Engineering Education Conference (EDUCON 2017), Athens, Greece, 26–28 April 2017; pp. 39–43. [CrossRef]
35. Yang, Z.; Zhou, Y.; Chung, J.W.; Tang, Q.; Jiang, L.; Wong, T.K. Challenge Based Learning nurtures creative thinking: An evaluative study. *Nurse Educ. Today* **2018**, *71*, 40–47. [CrossRef]
36. Lotz-Sisitka, H.; Ramsarup, P. Learning pathways and articulation: Early conceptual explorations and implications for research design (s). *SAQA Bull.* **2017**, *17*, 27. Available online: https://www.saqa.org.za/docs/bullet/2018/SAQA%20Bulletin%202017%20(1).pdf#page=37 (accessed on 14 July 2021).
37. Govorov, A.; Chernysheva, A.; Khlopotov, M.; Derkunskaia, S.; Arzumanian, A. Individual Learning Pathway Validation Based on the Syllabus. In Proceedings of the 26th Conference of Open Innovations Association (FRUCT 2020), Yaroslavl, Russia, 23–25 April 2020; pp. 1–7. [CrossRef]
38. Individual Learning Pathways. Available online: https://unevoc.unesco.org/pub/nqc_omnia_individual_learning_pathways.pdf (accessed on 28 June 2021).
39. De Royston, M.M.; Barron, B.; Bell, P.; Pea, R.; Stevens, R.; Goldman, S. Learning pathways: How learning is culturally organized. In *Handbook of the Cultural Foundations of Learning*; Routledge: London, UK, 2020; pp. 195–211, ISBN 9780203774977.
40. Sen, S.K.; Pookayaporn, J.K. Towards a SDG Compliant Framework for the Open Learning Modules: Experiences from Thailand and Philippines. In *Open and Distance Learning Initiatives for Sustainable Development*; IGI Global: Hershey, PA, USA, 2018; pp. 255–264. [CrossRef]
41. Adams, T.; Kishore Kumar, S.; Goggins, J.; Manton, R. Embedment of UN Sustainable Development Goals (SDG) within Engineering Degree Programmes. 2020. Available online: https://sword.cit.ie/cgi/viewcontent.cgi?article=1067&context=ceri (accessed on 28 June 2021).
42. Yin, R.K. *Designing Case Studies. Qualitative Research Method*, 3rd ed.; SAGE Publications: Thousand Oaks, CA, USA, 2009; pp. 359–386, ISBN 076192552X 9780761925521.
43. Cordts, M.; Omran, M.; Ramos, S.; Rehfeld, T.; Enzweiler, M.; Benenson, R.; Franke, U.; Roth, S.; Schiele, B. The cityscapes dataset for semantic urban scene understanding. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (IEEE 2016), Las Vegas, NV, USA, 27–30 June 2016; pp. 3213–3223. [CrossRef]
44. Minaee, S.; Boykov, Y.Y.; Porikli, F.; Plaza, A.J.; Kehtarnavaz, N.; Terzopoulos, D. Image segmentation using deep learning: A survey. *IEEE Trans. Pattern Anal. Mach. Intell.* **2021**. [CrossRef] [PubMed]
45. Bochkovskiy, A.; Wang, C.Y.; Liao, H.Y.M. Yolov4: Optimal speed and accuracy of object detection. *arXiv* **2020**, arXiv:2004.10934.