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► **To cite this version:**

Maud Rio, Tatiana Reyes, Yacine Baouch, Romain Colon de Carvajal, Vincent Robin, et al.. Integrating Sustainability in Industry of the Future Technological Learning Programs - A Platform to Co-create and Mutualise Course Experiences. 28th International Sustainable Development Research Society Conference - ISDRS, Jun 2022, Stockholm, Sweden. hal-03820672

HAL Id: hal-03820672

<https://hal.science/hal-03820672>

Submitted on 19 Oct 2022

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Integrating Sustainability in Industry of the Future Technological Learning Programs

A Platform to Co-create and Mutualise Course Experiences

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Abstract

This research investigates the adapted support, content, and context to integrate sustainability into engineering courses aligned with sustainable future requirements for industries. Three main barriers to the dissemination of knowledge on sustainability to higher education lecturer are detailed in this paper. To face them, a collaborative proposition has been formulated by the twelve academic researchers and collaborators involved in this project. The proposition confers three objectives: to facilitate the diffusion of sustainability issues in engineering courses for higher education, to develop and maintain a sharing platform, and to secure a contribution and co-learning network of contributors. The paper presents the first experimentations conducted with teachers and students, covering the basic-level one-sustainability skills for engineers formalised on a creative common software developed on a sharing platform hosted in France. Results show that behind the French engineering community involved in sustainability issues, the sharing principles are strong values to develop and maintain sustainability training over the year.

Keywords: Design for sustainability, Ecodesign, Engineering Education, Collaborative Network, Common

1. Introduction

The socio-technical issues related to sustainability in today's industrial shaped worldwide economy required massive changes to refocus in a safe operating space that is the Earth (Steffen, 2015). The ET-LIOS project financed by the French National Research Agency in 2020 supports sustainability in engineering to face the upcoming evolution for future industries. Six modules cover fundamental technological engineering skills, including one module on sustainable and responsible engineering for industrial actors. This paper focuses on this last module that aims to provide open-source teaching materials, and to train higher education teachers so that they can integrate sustainability (i.e. socio-ecological on short, medium and long-term) issues into their courses.

The research question investigated in this research is: how to support the integration of sustainability into engineering courses aligned with sustainable future requirements for industries?

Three main barriers to the dissemination of knowledge on sustainability to higher education lecturer have been identified at the starting point in this research paper. Firstly, there is a plethora of fragmented course materials. However, their formats and contents are not adapted to properly fit the existing technological courses covered by teachers. Secondly, available courses on sustainability are scattered in several platforms. Concerned with a lack of time, and with very limited guidance support, higher education lecturers are therefore struggling to choose the training material in sustainability that would fit their discipline. The sequence to start with and the level of socio-ecological issues to address are unclearly prescribed. Thirdly, the existing materials rarely allow teachers to share their own skills and compose their course efficiently. These three main issues occur in the context of a sudden rising knowledge production of sustainability in engineering. An integrative approach of such contents has therefore been identified as a key requirement to answer the research question.

This research paper therefore presents the collaborative proposition formulated by the twelve academic researchers and collaborators involved in this project to overcome these issues faced by engineering lecturers willing to integrate socio-ecological aspects into their engineering teaching. The proposition is meant to cover the following three objectives: to facilitate the diffusion of sustainability issues in engineering courses for higher education, to develop and maintain a sharing platform, and to secure a contribution and co-learning network of contributors.

Results presented in this paper show that the construction of the pedagogical materials allows identifying the targeted competences, the acquisition level adapted to an existing course, and additional pedagogical content organised on available strands. The proposed structuration supports teachers to elaborate sustainability-related contents in a flexible manner, and collectively. Teachers are enabled to pick and choose from a coherent pedagogical strand, to build their own course program, and to give it back to the community. In addition, an open-source collaborative platform supported by a trustable engineering network widely used in France (S.mart network: [website link](#), consulted on the 28th of

April 2022: www.s-mart.fr) support the teaching materials. Engineering lecturer can build, feed and share their courses and experiences within the engineering community. Feedback is requested in return to enable the hybridisation of contents across disciplines. The first experimentations conducted with teachers, and students are illustrated in this paper.

Section [2](#) presents the research context of the urgency for an integrative skill's sustainability-based approach in engineering teaching. Section [3](#) investigates the issues of sustainability knowledge dissemination faced by engineering teachers. Section [4](#) details the proposition of this research to overcome those issues and illustrates the application of the method proposed by an experiment conducted from March to June 2022 in engineering schools in France. The last section [5](#) concludes on the output of this research paper, and summarises the perspectives envisaged by the French community to ensure the future of the contributor network initiated, and its potential international connections.

2. The urge for an integrative skill's sustainability-based approach in engineering teaching

Faced with the ecological emergency (Steffen, 2015), and more particularly the climate emergency (IPCC, 2022). Immediate transitions of our (economic, political, cultural, etc.) models must take place at several levels of our society. For several years, initiatives with a more radical change objectives have emerged.

The Shift Project's transformation plan for the French economy (The Shift Project, 2022a), as well as the négaWatt scenario (Association négaWatt, 2021) are two relevant contemporary illustrations in France of the considerable and complex transformations required in the economy in the coming years. Huge transformations may lead to unpredicted changes.

2.1. Engineers and Sustainability

In these well-nigh perceived issues of sustainability, the industrial system actors are facing a major contradictory injunction: integrating the long-term consequences of their activities on the environment, in the very short term into an extreme competitive market focused society. Industrial system actors ask for ambitious training to support them in bringing immediate concrete corrective actions, as well as being competent to lead profound changes in their activity. Complementarily at universities and engineering schools, training in sustainability engage this massive socio-technical-economic transformation required with the future engineering generation (Grimal et al., 2020).

2.2. Education and Sustainability

Many countries have given a prominent place to education for sustainable development (ESD) in their courses. From an early age and throughout their training course, learners are called upon to understand environmental, economic and social issues and to be trained in selection and decision-making. France and other European countries have changed their educational systems in order to integrate the concepts of sustainable development. ESD appears in programs from primary school to university with the aim

of helping children, teenagers and young adults to identify their ‘sustainable values’, aligned with ‘the five disciplines of learning organisations’ report published in 1990 (Senge, 1990), and with the French University Guide for Sustainable Development and Societal Responsibility published in 2016 (CGE / CPU, 2016). Such educational programs clarify the causal links between the acquired knowledge, and the societal practices in sustainability that occur. Importance is given to the improvement of complex thinking with forward-looking and systemic visions of the problems to be solved, as presented in ‘the six dimensions of teaching the Great Transition’ (FORTES, 2020), the ‘skills for sustainability’ (Quelhas, 2019) as well as ‘the four areas of the Shift Project’ (The Shift Project, 2022).

2.3. The Dissemination of Knowledge of Sustainability to Higher Education

Integrating sustainable development into technology curricula is slow and difficult (Rose et al., 2015). Different approaches presented by Lozano and Young (2013) are experimented today:

- Through a partial coverage of environmental and social issues in an existing course.
- In a dedicated sustainable development course added to the curriculum.
- Sustainable development presented as a concept in existing disciplinary courses.
- Sustainable development topics offered as a specialisation within the framework of specific training within an institution.

Study conducted by the Think Tank ‘Shift Project’ indicates that only 7% of French university courses address environmental issues in their training (Vorreux et al., 2019).

The most popular approaches are either top-down based on lectures explaining the challenges of sustainable development, or transversal teaching elements relating to sustainable development in the courses of teachers volunteering. Sometimes, courses offer a specialisation module on environmental aspects (e.g. technological education at the master's level focusing on eco-design and life cycle analysis). Other countries such as Denmark switch from a ‘nice to have’ to a ‘need to have’ topic in the curriculum (Olsen et al., 2018). In Mexico (Lozano and Lozano, 2014) or Spain (Segalàs and Sánchez-Carracedo, 2020) universities are trying to establish Bachelor curricula allowing the integration of sustainable development in technological training.

From these experiments, an additional approach to integrate sustainable development into technological training has been formalised by Lozano and Young (2013), and Lourdel (2005): to develop a specific and integrated program, based on sustainability, which targets the demands of engineering professionals with this expertise.

The adapted pedagogical format to support interdisciplinary skills learning is still questioning students and teachers.

A diversity of lessons about climate change or energy efficiency topics are usually delivered in engineering schools. The environmental dimension of engineering is supported by methods to assess technologies: clean technologies, environmental impact assessment, efficiency, renewable sources, etc.

However, pedagogical methods to support engineering students to find their role in this socio-ecological transition are rarely available and the associated ethics, the governance of such technology usage in the society, as well as the responsibility of the engineer in making a technological choice is barely mentioned in class, or not systematically addressed.

2.4. Teaching Sustainable Issues in Engineering

In this context, how to better support the integration of sustainability into engineering courses aligned with sustainable future requirements for industries to move towards socio-ecological issues? Three main issues related to the dissemination of sustainability skills in engineering curricula have been identified: 1) training, 2) technical and 3) operational. The analysis of these three issues in this section will allow clarifying the three main scientific barriers addressed in this paper.

2.4.1. Training Issues

To be competent to train students, teachers themselves need to be trained to sustainability. Studies published in 2021 show the lack of knowledge and competences on topics related to sustainability assimilated by teachers (Imara and Altinay, 2021). For Rampasso et al. (2018), eleven difficulties related to the integration of sustainability in engineering education have been noted. In these difficulties some are related to pedagogical aspects and specially the ‘lack of access to appropriate and constantly updated didactic material that contemplates all sustainability strands for engineering courses’ (Fenner et al., 2005; Nowotny et al. 2018).

Two surveys targeting engineering teachers from public and private spheres were conducted in France in 2021-2022 as part of this project. The results show the current difficulties faced by engineering teachers in the French context within the S.mart community (website links, consulted on the 28th of April 2022: www.s-mart.fr). Results were initiated during Perpignan (2021) doctorate research project. The analysis of the answers to the surveys showed that the majority of the difficulties identified by Rampasso et al. (2018) at the international level are also occurring in France. The interviewees expressed their lack of training and the lack of educational resources available to them to address the systemic vision, the historical, ethical and technical aspects related to sustainable development. This finding corresponds to the third and ninth difficulties stated by Rampasso et al. (2018). More than 80% of respondents were looking for training to help them integrate sustainability more precisely into their teaching.

Teachers ensure awareness and knowledge transfer by promoting deliberative exchanges, contacts and interactions with scientists, reasoning about controversies and ‘fake news’ through the implementation of projects (Liu et al., 2015; Monroe et al., 2019). Teachers endorse a key role as students are often open-minded and interested in the scientific, social and ethical aspects of sustainable development and climate change. As shown by Tolppanen and Aksela (2018), teachers are sometimes confronted with

highly challenging student questions. Bürgener and Barth (2018) demonstrate the importance of the initial training of teachers and their access throughout their career to working methods, resources and tools allowing them to train and progress. Those crucial elements improve the quality of consideration of sustainability issues in training.

The teachers' training is therefore an additional major challenge in order to offer sustainable engineering education that is relevant, adapted to the students' needs and to support companies to handle the challenge of sustainability. Training a teacher cannot be reduced to providing a 'ready-to-use kit' of knowledge or lessons. In previous cited research, surveys showed that teachers are looking for a training process that helps them to design lessons as precisely as possible to their reality and to adapt the level and expectations of the students they are facing. This is especially true in the case of sustainability issues where knowledge is evolving extremely quickly and requires a holistic and interdisciplinary vision.

2.4.2. Technical Issues

The main technical issues faced by teachers are firstly the plethora of course materials available. However, their format and content are not adapted to properly fit the existing technological courses they master. Secondly, available courses on sustainability are scattered in several platforms (e.g. fun-mooc.fr, uved.fr, eduscol.education.fr, enseignerleclimat.org). Concerned with a lack of time, and with very limited guidance support, higher education lecturers are therefore struggling to choose the training material in sustainability that would fit their discipline. The sequence to start with and the level of socio-ecological issues to address are unclearly prescribed.

2.4.3. Social Issues

First, the lack of engagement and supporting consideration by teachers, by program managers, engineering or technical schools, of the socio-ecological issues is a stumbling point. Inertia to modify academic programs is quite challenging to anyone willing to integrate them in their teaching activities. Secondly, the existing materials rarely allow teachers to share their own skills, and compose their course efficiently, whether it is because colleagues do not want to share teaching materials or because it is considered as the property of the school that does not want to share it outside the educational institution.

2.4.4. Scientific Barriers of Knowledge About Sustainability to Engineering Education

Three main barriers to the dissemination of knowledge on sustainability to engineering education have been identified studying the technical, social and training issues in the previous sections. Firstly, there is a plethora of fragmented course materials of different formats and contents, and not adapted to properly fit the existing technological courses covered by teachers. Secondly, the courses are scattered in several platforms, with very limited guidance support to fit sequences into existing disciplines

material at a certain level. Thirdly, the existing materials are not meant to be shared to compose a course efficiently. The objective of the proposition developed in this paper is to overcome these three barriers, based on an integrative and holistic approach tested in France.

2.4.5. A Proposition for Teaching Sustainable Issues in Engineering Teaching

The proposition of this paper is a framework presented in the following section, and illustrated (on the first objective) by an experiment conducted from March to June 2022 in engineering schools in France. The framework has been developed collaboratively in France through the ET-LIOS project financed by the French National Research Agency in 2020, aiming to support sustainability in engineering to face the upcoming evolution for future industries. Six modules cover fundamental technological engineering skills, including one module on sustainable and responsible engineering for industrial actors that is the focus of this paper. This last module aims to provide open-source teaching materials, and to train higher education teachers so that they can integrate sustainability (i.e. socio-ecological on short, medium and long-term) issues into their courses.

3. Conceptual Framework: Integrating Sustainable Issues in Engineering Training

3.1. Research Objectives and Proposition Specification

The framework proposed aims to meet three main objectives with the related propositions are specified in the following:

- **The objective 1** is to facilitate the diffusion of sustainability issues in the existing engineering courses for higher education. The proposed solution is to develop a specific and integrated skill-based program for sustainable issues. The program is developed in an editorial chain software called Scenari-Opale (Crozat, 2007).

Specification to satisfy objective 1: skills and competencies should be defined, modules should be prototyped and experimented with teachers, teachers and students should be trained, and the acquired skills should be evaluated.

- **The objective 2** is the necessity to develop and maintain a sharing platform: the resulting collaborative sharing platform called 'Ecocloud' is currently tested by the S.smart community in France.

Specification to satisfy objective 2: the design requirements of the teaching material sharing platform should be specified, the software functions and user interface should be tested, the capacity to maintain the platform has to be ensured in medium to long-term.

- **The objective 3** is to secure a contribution and co-learning network, addressed by the creation of a 'common' as defined in the field of research initiated by Ostrom (1990).

Specification to satisfy objective 3: the communication of the project should be ensured, the contributors to the teaching material and platform should be identified, the network to maintain the involved teachers, researchers, students, engineers, should be maintained over time.

Figure 1 summarises the framework addressed in this paper and the related research project agenda followed.

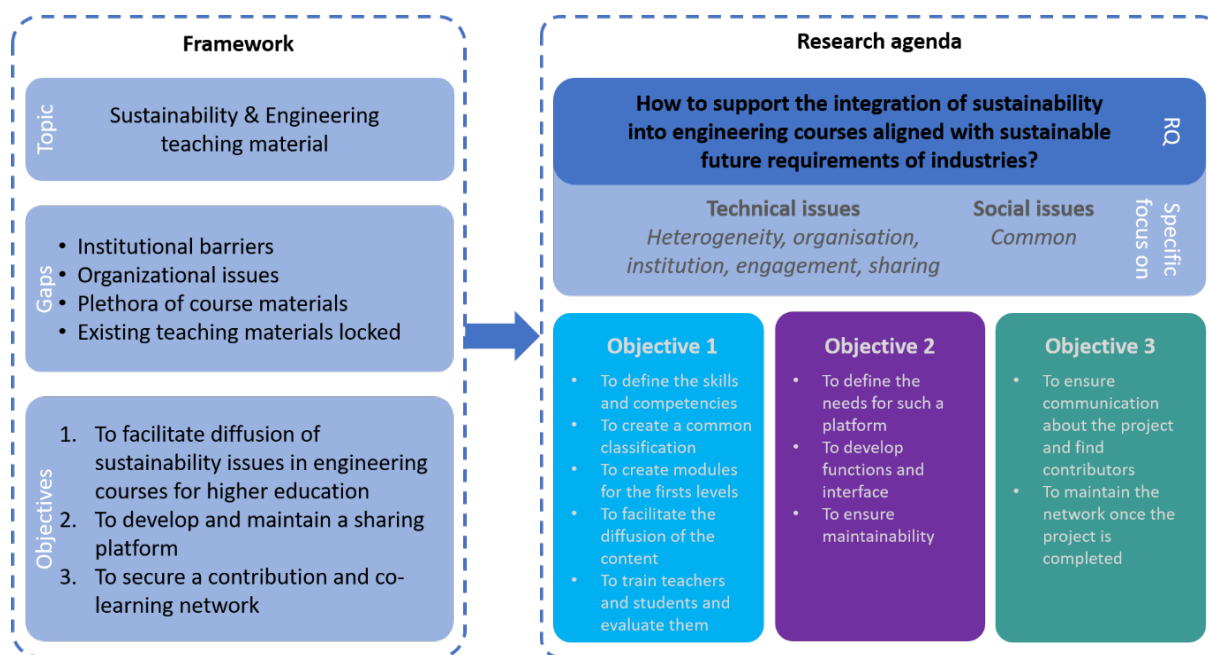


Figure 1: Research proposition overview

3.2. Integrating the Challenges of Ecological and Social Transition into Teaching

The first objective aims to train both teachers and students to sustainability with a proposed skills-based program and its contents.

3.2.1. A skills-based Framework to integrate sustainability issues into higher education training

A skills-based approach appropriated to interdisciplinary training has been chosen. The learning acquisitions are targeted by detailed objectives, allowing teachers to understand the ins and outs of sustainability issues (concrete benchmarks), and to easily integrate them into their teachings (Blömeke, 2013; Lozano, 2012). Teachers are able to combine resources of different nature: knowledge, know-how and interpersonal skills together. Different levels of skill can also be combined, giving rise to observable results in learners (Barabel, 2020).

This framework was elaborated based on five sustainability-skill guides: the five disciplines of learning organisations published by Senge (1990), the sustainable development and societal responsibility University French skills guide published in 2016 (CGE / CPU, 2016), the skills for sustainability

recommendations of Quelhas (2019), the six dimensions of teaching the Great Transition published in 2020 (FORTES 2020), and the four areas of The Shift Project report (2022b).

Each skill is described in a fairly similar way in these studies, with some variations in terminology depending on the sources, summarised in Table 1.

Table 1: Corresponding skills of five skill-based frameworks in sustainability

Categories of skills used in the skill-based framework	The 4 areas of the Shift Project (2022b)	The Six Dimensions of the Great Transition (2019)	Skills for sustainability of Quelhas (2019)	Skills guide of the DD&RS CGE/ CPU (2016)	The five disciplines of a learning organisation by Senge (1990)
System thinking	Systemic and transdisciplinary approach	Oikos: the Earth, the common home.	Systemic thinking	Systemic	Systemic thinking
Ethics		Ethos: Discern and decide the right values.	Self-awareness	Ethics and Responsibility	personal mastery
Prospective	Historical & prospective approach	Logos: interpret, criticise, imagine.	Vision of the future; critical thinking	Prospective	Shared vision
Changes (sustainable design)	Mobilising engineering techniques	Nomos: measure and govern.	Ability to solve problems; normative skills	Competence of changing things	Changing Mental Models
Collective actions	Implementing a sustainable strategy to respond to the challenges	praxis: acting to meet the challenges. Dynamis: reconnection to oneself, to others and to nature	Strategic competences; working in an interdisciplinary group	Collective skills	Team learning

From this literature review, the skills-based framework covers **the system thinking, the prospective vision, the ethic, the change management, and the action skills categories.**

The system thinking engages a worldwide vision answering the capacity to understand the Earth systems and the consequences of the human way of living on the natural ecosystems. The aim is to learn the general skills in sustainability and to be able to develop a personal thinking about this. The main

disciplines are biology, the ecology (environmental sciences) addressing ecosystems, agroecology topics, as well as the notion of planetary boundaries (Steffen, 2015).

Developing the **prospective vision** aims to support the capacity to adopt an historical approach of the socio-ecological stakes, of the Anthropocene era, and then to build a critical view, allowing developing a prospective vision. This skill helps to be capable of preparing tomorrow's world, referring to scenarios, as well as future visions, by analysing, evaluating them, and anticipate consequences. History, sociology or economy are key disciplines in that learning process. Topics include Collapsology, the rebound effects or Jevon paradox, as well as the Anthropocene sciences in general.

The **ethic** refers to the disciplines of psychology and philosophy that address the personal engagement and responsibility of the engineer (or teacher in engineering). The aim is to think about the role of the engineer, support the capacity to evaluate actions, and to face the individual feelings and desires in an introspective manner. The values and responsibilities as an engineer, and as a human being is questioned. Topics include personal development as well as societal responsibility.

The skill referring to **change** aims to question the engineering technic mobilisation to answer a societal objective. In this view, technic is non-neutral and has a political effect. Disciplines involved include the epistemology, the design sciences, the sociology, economy and political standards. Life cycle assessment, ecodesign are subjects that are linked to this capacity to develop critical thinking and adopt a position facing changes, based on an environmental-impact assessment result for instance.

The last category of skills concerns the **action** and aims at answering the current sustainable issues by specific action mode. The capacity to co-design viable solutions, in an inclusive manner, equitable and sustainable ones, in a complex thinking manner describe this skill which can be acquired and used in all discipline. It is particularly useful in the student's project.

Table 2 summarises the information on the aforementioned skills into different categories: the aim, the covered topic, the main disciplines related, the describing skills' verbs, and the main topics addressed.

Table 2: Main skills for a sustainable foundation adapted to engineering fields

System thinking- worldwide vision	Prospective – vision of the future	Ethic	Change – e.g. Sustainable design	Action
Aim: learning general skills in sustainability and being able to direct a singular thinking.	Aim: adopting an historical approach, then a prospective one. Understanding the socio-ecological stakes of the Anthropocene era and developing critical views.	Aim: thinking about the role of the engineer, evaluating his/her own actions and facing his/her proper feelings and desires.	Aim: mobilising engineering technic and considering their political non-neutrality, so as to answer societal objectives (Shift project).	Aim: answering current issues by specific action modes. Co-designing viable solutions, inclusive and equitable ones, supporting

				sustainability.
Answering: how Earth system works? Which impacts and consequences of our ways of living?	Answering: how to prepare for tomorrow's world, based on scenarios and future visions?	Answering: what are my own values/my responsibility as an engineer and a human being?	Answering: How to enable change?	Answering: which actions carrying-up to support the transition toward an ecological state?
Main disciplines: biology, ecology (environmental sciences)	Main disciplines: History, sociology, economics	Main disciplines: psychology, philosophy	Main disciplines: epistemology, design, sociology, economy, politics (norms, standards)	Main disciplines: all
Verbs used To learn, to understand	Verbs used To analyse, to evaluate, to anticipate	Verbs used To discern, to engage	Verbs used to normalise, to design, to adopt a position facing changes, to criticise (to develop critical thinking).	Verbs used To act, to co-design, to address complex issues, to propose, to try
Main topics addressed: Ecosystems, agroecology, Planetary boundaries	Main topics addressed: Collapsology; rebound effect /Jevons paradox, Anthropocene sciences	Subject addressed: Personal development Societal responsibility	Subject addressed: Perma-engineering, low-tech, Life Cycle Assessment (LCA), Eco-design	Subject addressed: Grassroots initiatives. Any subjects suitable for student projects

3.2.2. A taxonomy for Efficient Customisation and Use of the Scenari Software

An editorial chain software has been used to support this content, called Scenari-Opale (Crozat, 2007). Scenari is based on Extensible Markup Language (XML) and is an open-source software. One of the main Scenari's functionality is to enable the content of the form (display). The taxonomy inherited from the use of this software comprises three levels: strands, modules and courses.

First, the 'strand' covers a pedagogical goal and corresponds to students work time slot of 5 to 15 minutes. The format may support a definition, a diagram, a video, a small quiz, etc. Each strand has an adaptable content that has to be usable in an independent manner and can be used to complement an already existing course. A strand owns a pedagogical goal. This goal is defined in order to reach a skill. A strand is composed of content but also metadata. There are Learner's level (beginner, intermediate or advance), Time slot work, Intended resources (material, digital...) and tags.

Second, the 'module' refers to an assembly of strands. A standard example would be a two hours' canonical lecture or tutorial. Third, the 'course' gathers or combines several modules. A course can cover for instance a six-month student engineer program.

The major contribution of the framework is that the competencies are built based on this taxonomy (courses, modules and grains) which makes the content of the courses flexible, dynamic and appropriable by the teachers.

Scenari's functionalities allow managing any strands, modules and courses and to publish them in different formats, such as a web-based, Portable Document Format (PDF), Sharable Content Object Reference Model (SCORM) that is a set of standards used for elearning software products. Therefore, the proposed software allows the customisation of the educational content proposed by the ET-LIOS project (covering the various modules for the Future of Industry).

3.2.3. Structuration of the Educational Content

To define an educational content available on a dedicated platform, a state of the art of lessons related to the various themes of the transition has been produced.

The content lists all copyright-free modules provided in the teaching units included in the proposed in the sharing platform: module units provided by the partner of the project, MOOCS, etc.

Finally, each skill is subdivided into several courses. Each course is divided into modules that are divided into strands. Strands are the smaller subdivisions and contain the teachings of the state of the art of lessons related to sustainable issues in engineering teaching.

3.2.4. Training Content and Methodology Specification

The training content for students is similar to the one for teachers. A skilled based program is proposed to teachers and students. The objective is to enable participants to acquire the level 1* skills for each of the five-sustainability skills related to sustainability issues in engineering.

The formation takes place within the framework of existing teaching units. The educational content experimentation phase is carried out during several training sessions. Each session occurs in a distinct higher education place: either from an engineering school or a University in France. The training is displayed in a hybrid format (face-to-face and remotely at the same time).

The sessions alternate with lectures, debates and participatory workshops presenting and practising contents from the educational modules. The training session also offers the opportunity for teachers to use the Scenari-Opale software. During this dedicated workshop, they are invited to create their own educational content based on the existing educational strands, and on their own case studies.

The tree levels of skills defined in this study are the following:

*Level 1: Become aware, conceptualise knowledge and skills, question yourself.

Level 2: Analyse a given problem with a critical eye.

Level 3: Position yourself in relation to a given problem, solve complex case studies and propose solutions and means of action.

3.3. Developing and Maintaining the Ecocloud Collaborative Platform over the Years

As part of the ET-LIOS project, the Ecocloud collaborative platform hosts all the aforementioned courses. Ecocloud is a collaborative platform supported by the Scientific Interest Group (SIG) S.mart. It was born in May 2016 within the initiative of the interdisciplinary research team working on the transition towards the sustainability of socio-technical systems (CREIDD) of the University of Technology of Troyes. This platform offers a space for sharing material, methods, tools, and networking between academic, private actors and grassroots initiatives, about sustainable development in the context of the industry of the future. The courses are primarily intended for teachers wishing to integrate sustainability into their practices, but the resources will also be available to the general public.

They will also be made available to the community under a specific creative commons license: CC-BY-NC-SA 4.0. This license is composed of 4 acronyms: 'CC' means 'Creative Commons', 'BY' means that 'licensees may copy, distribute, display, perform and make derivative works and remixes based on it only if they give the author or licensor the credits (attribution) in the manner specified by these', 'NC' for 'Non Commercial' means that 'licensees may copy, distribute, display, perform the work and make derivative works and remixes based on it only for non-commercial purposes' and 'SA' for 'Share Alike' means that 'licensees may distribute derivative works only under a license identical to [not more restrictive than] the license that governs the original work'.

This public copyright license will ensure that the content provided on the platform is reusable, modifiable and distributable to as many people as possible. This concerns the courses' strands developed for each skill, as well as the exercises and the case studies. Therefore, the Ecocloud platform is a pool of resources for research and teaching, already used.

In medium to long-term perspective, any member of the SIG S.mart is invited to complete the training materials and case studies initiated during the ET-LIOS project, as well as to enrich the existing strand database. As of the date of the first experiment on March 30, 2022, around thirty modules have been created in Scénari and made available on the Ecocloud platform in the following formats: PDF, presentations, and websites. These modules have been created thanks to the participation of many contributors from partner universities.

3.4. Developing a Contributor Network

The third objective is to ensure the network continues and contributes over time. A network of contributors and co-learners are federated during the ET-LIOS project and integrated into the SIG-S.mart national network. Keeping-up the contributive dynamic is challenging. A step-by-step roadmap throughout the training sessions calendar is planned, associated with a contributor's membership chart that clarifies the values supported by this network and the engagement of the initiative. Trained teachers and students can then become contributors. They are invited to enrich the Ecocloud platform. In return they train other academics depending on their level of involvement and the time, they are willing to invest in accelerating the integration of sustainability in educational programs.

Behind this notion of community sharing is addressed the issue of the commons that is the topic of the following sub-section.

3.4.1. Using the Common Concept to Ensure the Perennity of the Sharing Community

The concept of 'common' refers here to the field of research initiated by Ostrom (1990). Through this concept, she has shown that there are modes of management that escape the dichotomy between private and public management. In an institutional approach, she has shown that commons are preserved by rules set by communities that use these resources. Her work initially focused on 'natural' commons such as forests, fishing sites, etc. Natural common share 'common-pool resources', i.e. non-exclusive, but rival resources. This theoretical framework was then extended to think about knowledge common (Hess & Ostrom, 2007), particularly in relation to the development of digital technology. Whether natural or 'immaterial', commons generally refer to the articulation of three elements: a shared resource, a community that manages the resource, and rules of governance. The difference between knowledge commons and the others is that the use of knowledge is non-substitutable: one can use knowledge without preventing someone else from using it. On the contrary, each new usage can be a source of enrichment for others.

This theoretical framework is useful to underline some issues identified previously, as part of knowledge commons. The first specificity is legal, and concerns property. The common movement unity is the fight against enclosures, that is, against the privatisation of common utility resources. In terms of knowledge, this consists of breaking out of the logic of intellectual property. It is about putting resources in open sources so that they can be reused, or even modified by others. The framework of Creative Commons licenses (CC) allows protecting the use of an intellectual resource, while making it available. In the educational field, UNESCO called this 'Open Educational Resources', defined as 'learning, teaching and research materials in any format and medium that reside in the public domain or are under copyright that has been released under an open license that permits no-cost access, re-use, repurpose, adaptation and redistribution by others' (UNESCO, 2019). Rather than being a teacher building a course alone in a corner, and declaring being the sole owner, this approach proposes another logic. Beyond the legal aspect, there is the question of the constitution of a dynamic within the teaching community. The challenge of this research raised in this paper is indeed to build a community of practice

within the teachers. It is not enough to share resources. It is also necessary to create a community. Resources are only one element among three: the community, the resources and the governance between individuals among them and with the resources.

3.5. Validity of the Framework

Referring to the various methods of research validation available in the literature, the following validation techniques were selected for each objective to demonstrate the relevance and consistency of the research proposal:

- **objective 1 validation criteria:** diffusion of sustainability issues in the existing engineering courses for higher education.

Following-up on the training sessions, teachers and students are asked in a short-term period to give feedback about the number of educational contents they introduced in their teaching, as well as the number of students trained (or to be trained in the coming year).

The assessment of skills acquired during the training sessions is based on a self-assessment grid covering the five domains of sustainability, identified in this research to support an ecological and social transition in engineering fields (cf. Table 1). This self-assessment grid is completed by the participants at the beginning and end of the training sessions to compare the levels and identify the skills acquired. For each competence, the trainer rates from 0 to 4 depending on his level of mastery of the skill: (0) I do not master the skill (1) I understand the skill (2) I master the skill a little (3) I master the skill well (4) I master the skill perfectly. A post-training session follow-up is then carried out to assess the number of educational contents introduced in teacher activities as well as the number of students trained.

- **objective 2 validation criteria:** relevance of a sharing platform.

In order to estimate the impact generated into the S.smart community, the number of weekly visits and the number of educational strands create and downloaded will be evaluated.

- **objective 3 validation criteria:** the existence of a contribution and co-learning network.

The assessment indicators are the number of contributors, and the individual average of devoted time to contribute to the network activities (transforming training, enriching exciting, integrating new strands, helping others, giving feedback, sharing ideas, disseminating, assessing proposed contents and improving, etc.). An estimation of the training material disseminated by additional contributors, distinct from the initial project partners, is an additional impact indicator. Also, the number of weekly visits, the number of educational strands create and downloaded is installed to estimate the impact generated into the S.smart community.

4. Results and Discussion

During the spring semester 2022, preliminary experiments were launched to begin testing objectives 1 and 2 with the following results.

The first experiments occurred from March to early June 2022 revealed the difficulty to engage teachers in a two-or three-day training session. The participants of the first experiment conducted at the University of Technology of Troyes were either in charge of teaching programs concerned with the necessity to integrate sustainability issues into the courses, as well as teachers searching for being trained to sustainability issues (in a coherent and holistic view) and searching for training materials that would be adapted to their domain. Additional participants were PhD students and engineers intervening as external lecturer, concerned by the topic and willing to change their training material to better face the challenge of sustainability. The program offered various conferences and participatory workshops covering the main concepts to be acquired in the five categories of skills.

In a conference mode, the following questions were asked to the participants: how to introduce sustainability issues into teaching? What are the main planetary issues of our time? What are the main eco-design and environmental assessment techniques? Which engineering ethics to adopt? At the end of the training session, several participants in charge of teaching programs felt an urge to accelerate the integration of such training into their programs. Emotions arose in participants when the planetary boundary issues were explained. As the research agenda was to firstly introduce level 1 skills about sustainability, and secondly to propose some solutions to facilitate this training material to be developed, shared and evolved, this emotion was not locking participants in a despair situation. This sadness about the massive impacts occurred by the industrial society, causing irreversible damages on the ecosystems conditioning the liveability of the Planet, could therefore be turned into an energy of engagement.

Concerning the experimentation with the students, the contribution of knowledge in ecological and social transition could be carried out within the framework of already existing teaching units. The control group consisted of twenty vocational bachelor's students in engineering not trained in sustainability, nor transition to sustainability.

Educational workshops mainly targeting the sustainable design and change part were carried out. This public felt at the beginning little concerned with the themes of sustainability. The participants developed a strong interest in the disciplines of transition as well as enthusiasm for collective change along the training process. The results of the evaluation grid show the evolution of their skills between the beginning of the teaching (almost zero skills) and the end of the teaching (level 1 of the 'change management' skills acquired by a majority of the students).

5. Conclusions

This paper addressed the issues faced by engineering lecturers willing to integrate socio-ecological aspects of their engineering teaching material. Institutional barriers, organisational issues, in addition to the diversity of the course materials available to teachers that are not adapted to their contexts, prevent sustainability issues to be fully addressed in engineering schools and universities. The objective of the ET-LIOS research project introduced in this paper is firstly to facilitate diffusion of sustainability issues in engineering courses for higher education, secondly to develop and maintain a sharing platform and thirdly to secure a contribution and co-learning network. This research questions the support to integrate sustainability into engineering courses aligned with sustainable future requirements of industries. The originality of this research is to focus on technical issues, such as the organisation, the heterogeneity of material courses, the institution gaps, the personal engagements, the sharing visions, as well as the social issue, including the inertia to change academic programs.

To address this research question, the paper proposes a methodology for the construction of pedagogical materials allowing identifying the targeted competences, the acquisition level adapted to an existing course, and additional pedagogical content organised on available strands. Organised in a skills-based framework, teachers are supported to elaborate sustainability-related contents in a flexible manner, and collectively. Teachers that participated in the experiment could pick and choose from a coherent pedagogical strand, to build their own course program, and to give it back to the community. In addition to this methodology, open-source tools are made available on the 'Ecocloud' platform supported by a trustable engineering network widely used in France (S-mart network). In addition this sharing experience within the engineering community provides some feedback in return, enabling the hybridisation of contents across disciplines, experimented in real on students and reviewed by peers and confreres.

The proposed method covers distinctively the three objectives of this research. The associated assessment indicators have been explained and applied during the first experiments conducted from March to June 2022, of training sessions for sustainability and on the collaborative platform. The advantages and limitations of the first results obtained in this first experimentation occurred at the University of Technology of Troyes in March 2022. The role of academia appeared to be central to invite students building-up their aspirations as future engineers of a sustainable society, as well as engineers already part of the industry who are willing to rethink plurality, diversity and frugality. Such considerations are part of a sustainable way of living unbalanced with the whole living planet.

Finally, the issue of 'a' common created arises at several levels. At the software level: how to ensure that the platform is maintained over time? At the community level: how to ensure that the dynamics of contribution and co-learning endure? Some of these questions are related to governance issues: who

will host and maintain the platform? Who is willing to contribute, and on what aspect? These different aspects will have to be addressed in the following years.

In the systemic vision of sustainability, this initiative is meant to be connected to similar ones developed around the world. The research agenda is to extend the Ecocloud platform and the associated training material, and community-sharing network to other countries. Some material could be translated into different languages or associated with creative common material that deliver similar strand contents in another language, illustrated with additional sociocultural visions and experiences. The diversity of approaches may contribute to increasing the gap between the plethoric material courses available at the same time in worldwide universities. This diversity may also enable a number of connections to occur within the contributor network, to enrich contents, practices, build required controversies, in a systemic and ever-evolving format led by worldwide citizens.

Acknowledgements: Maud Rio: Writing – Review & Editing, Methodology, Investigation, Validation; Tatiana Reyes: Project administration, Funding acquisition, Supervision, Writing – Review & Editing, Methodology, Validation; Yacine Baouch: Writing – Original draft, Methodology, Investigation, Validation; Tom Bauer: Writing – Original draft, Methodology, Investigation, Validation; William Bernaud: Writing – Original draft, Methodology, Investigation, Validation; Romain Colon de Carvajal : Writing – Original draft, Methodology, Investigation, Validation; Elie Lemarquis : Writing – Original draft, Investigation, Resources; Alexandre Mege-Revil : Writing – Original draft, Methodology, Investigation, Validation; Catherine Perpignan: Writing – Original draft, Methodology, Investigation, Validation; Vincent Robin : Writing – Original draft, Methodology, Investigation, Validation; Paul Saada : Writing – Original draft, Investigation; Alexandre Gaultier: Reviewing & Validation.

Funding: This work was supported by the French Program of investments for the future: [grant numbers ANR-20-NCUN-0009].

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