Chapter

Engineering Education 5.0: Strategies for a Successful Transformative Project-Based Learning

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Abstract

Project-based learning has importantly helped to transform engineering education over the last decades, as it has been increasingly applied worldwide, as a fundamental methodology for shifting to student-centered engineering programmes. To enlighten the transition from Industry 4.0 to Society 5.0, and from Engineering Education 4.0 to Engineering Education 5.0, project-based learning (PBL) methodologies should also evolve. In terms of focus and topics selected for the PBL experiences, it is necessary to put forward the relevance of global challenges and to nurture a compromise for sustainability and ethical behaviour, while bringing students as close as possible to real multifaceted engineering problems. As regards connections with other educational methodologies, PBL and service learning (SL) are bound to hybridization and may benefit from innovative approaches, like the use of flipped classrooms, the promotion of gamification or the support of online resources and e-/b-/m-learning tools and methods. Complete PBL experiences will also synergize with and contribute to open-source engineering movements, like the "makers" movement, and will benefit from open software and hardware tools for increased educational equity. This chapter analyses and discusses trends in PBL methodologies, in connection with these new industrial and educational paradigms.

Keywords: project-based learning, service-learning, Industry 4.0, Society 5.0, educational innovation, Engineering Education 5.0, PBL5.0

1. Introduction

Technology is advancing at an extremely rapid pace, transforming societies, and reformulating all areas of education in the majority of the world, especially in the engineering field. Around a decade ago, the concept of "Industry 4.0" was proposed to summarize a set of industrial technologies from the fourth industrial revolution, linked to interconnected smart technologies, and evolving from the third (or digital) industrial revolution [1, 2]. Almost in parallel, the concept of "Society 5.0", in short: *a human-centered society that balances economic advancement with the resolution of social problems by a system that highly integrates cyberspace and physical space*, was proposed in Japan [3]. "Industry 5.0," the current industrial revolution, has been also recently proposed [4, 5], and is a consequence of applying the technologies from Industry 4.0, and their diverse successors, to the Society 5.0 paradigm.

"Education 5.0" also benefits from these contemporary technological resources and aims at constructing Society 5.0, solving problems through value creation and quality education worldwide [6], in connection with the Sustainable Development Goals and the Agenda 2030 [7, 8]. Education 5.0 is bound to affect all educational levels and areas. In the engineering realm, the shift to innovative scenarios, which promote a continuously evolving engineering education, capable of adapting to these non-stop technological revolutions, is of special relevance.

Accordingly, the concept of "Engineering Education 5.0" has been also just proposed as an educational paradigm [9]. In short: *Engineering Education 5.0 transcends the development and application of technology and enters the realm of ethics and humanism, as key aspects of for a new generation of engineers. Ideally, engineers educated in this novel educational paradigm should be capable of leading and mentoring the approach to technological singularity, which has been defined as a future point in time at which technological growth becomes uncontrollable and irreversible leading to unpredictable impact on human civilization, while ensuring human rights and focusing on the construction of a more sustainable and equitable global society*.

Taking into consideration recent engineering education transformations with international impacts, like the Conceive, Design, Implement, Operate (CDIO) initiative [10], it is necessary to put forward the relevance of problem- and project-based learning methodologies (PBL), which recreate the real professional life of engineers and train students for solving real-world challenges. Indeed, project-based learning has helped to reformulate engineering education over the last decades, as it has been increasingly applied worldwide, as a fundamental methodology for shifting to student-centered engineering programmes.

To enlighten the transition from Industry 4.0 to Society 5.0, and from Engineering Education 4.0 to Engineering Education 5.0, project-based learning (PBL) methodologies should also evolve:

In terms of focus and topics selected for the PBL experiences, it is necessary to put forward the relevance of global challenges and to nurture a compromise for sustainability and ethical behaviour, while bringing students as close as possible to real multifaceted engineering problems. As regards connections with other educational methodologies, PBL and service learning (SL) are clearly bound to hybridization and may benefit from innovative approaches, like the use of flipped classroom, the promotion of gamification or the support of online resources and e-/b-/m-learning tools and methods. Complete PBL experiences will also synergize with and contribute to open-source engineering movements, like the "makers" movement, and will benefit from open software and hardware tools for increased educational equity.

Towards a successful construction of "Engineering Education 5.0", this chapter analyses and discusses trends in PBL methodologies, in connection with these new industrial and educational paradigms. Besides, basic guidelines for synergically implementing PBL experiences within engineering programmes oriented to Society 5.0 and pursuing a global promotion of students' professional outcomes are also presented. Finally, several types of innovative PBL are described, numerous topics for implementation, covering most engineering specialties and professional roles, are presented, and useful supporting resources for professors and students are summarized. The gathered proposals are based on the author's personal experience and views, on inspiring discussions with colleagues and a systematic search within the literature, as regards modern engineering education.

2. Features of Engineering Education 5.0 and modern PBL

Engineering Education 5.0, according to its seminal publication [9], should be characterized by 16 interwoven key features listed in **Figure 1**. Some of these attributes have been also mentioned off late in relevant reports focusing on engineering education trends [11–13], which explain educational methodologies and learning styles quite connected to Education 5.0.

In the author's opinion, modern PBL should take account of these key features, to keep pace with the continuous evolutions within Engineering Education 5.0. At the same time modern PBL, built upon these elements, may liberate engineering programmes from the usually fixed frameworks and let them endlessly change, while supporting and mentoring the technological advances of Industry 5.0 for the successful construction of Society 5.0. Arguably, transforming PBL with Engineering Education 5.0 in mind, may turn out to be a very adequate strategy for empowering and deploying the technological revolutions ahead, whose positive industrial, economic, and social impacts can be essential. Counting with engineering education as one of the more relevant drivers of social change is always rewarding.

Figure 2, in alignment with other studies focused on strategies for the design and implementation of successful and transformative PBL [14–16], presents a selection of good practices for adjusting PBL methods to better consider the different pivotal aspects of Engineering Education 5.0. For instance, modern PBL in the Engineering Education 5.0 paradigm should change dynamically, evolving with technologies, as the state-of-the-art rapidly flows. To this end, annual modifications to the projects' topics present a double intention: on the one hand keeping the PBL experiences alive, helping students to focus on avant-garde techniques and methods; on the other, avoiding malpractice and copying or taking too much inspiration from previous years' results. Besides, modularity and flexibility are necessary for promoting resource-effective and personalized education and for swiftly spreading PBL across engineering programmes and universities. These aspects can benefit from counting with a fundamental or core module (i.e., engineering design methodologies for innovative product development), which may be central to different

Figure 1.
The 16 interwoven key features of Engineering Education 5.0.

1. Dynamic & continuously evolving
- Change the projects' topics every course to keep the experiences alive and to avoid copying.
- Continuously monitor learning results and outcomes, correct and improve as needed.

2. Modular & flexible
- Design a fundamentals or core module that can be the central part of different PBL experiences.
- Combine modules for adapting successful PBL experiences to different engineering programmes.

3. Personalized
- Let students select the needs to work on and the specific topics for their projects.
- Be flexible to incorporate specific learning activities, as required for concrete projects.

4. Sustainable & caring
- Include a learning module focused on the evaluation of sustainability and social impacts.
- Ask students to perform quantitative assessments about projects' sustainability and impacts.

5. Knowledge- & outcomes-based
- Complement core modules on engineering design and project management with technical issues.
- Dedicate time to focus on soft skills: teamwork, communication, creativity, leadership…

6. Holistic
- Modern PBL should be integrative, allowing students to apply scientific-technical knowledge from a whole degree, for which projects should be necessarily complex and demanding.
- PBL experiences should help students master technological tools used in real professional practice.

7. Humanistic
- Best projects tell a personal stories, help students focus on human-centered design strategies.
- Consider projects' connections to art, literature, cultures, history… relevant and evaluate accordingly.

8. Guided by ethics
- Introduce students to the more relevant regulations and standards in their projects' areas.
- Motivate students to design according to standards and to work in a socially responsible way, behaving also ethically with their peers, especially through peer-assessment activities.

9. Collaborative & open-source
- PBL benefits from sharing best practices, for which delivering projects' results (products & processes and their subsystems) as open-source materials may be strategic.
- Motivate students to collaborate with colleagues, to use and share open-source results.

10. Involving international experiences
- Encourage students to participate in international PBL competitions and link them to credits.
- Foster the application of e-twinning methods to PBL experiences, create international PBL courses, benefit from e-/b-/m-learning methods for incorporating invited international speakers.

11. Involving external stakeholders
- Connect the PBL experiences to real social & industrial needs, involving companies as sponsors.
- Arrange a team of external advisors that help to monitor and evaluate students' outcomes.

12. PBL hybridized with service-learning
- Ideally, students' projects transform society through science and technology: focus on real needs.
- Involve, as part of the advisors' committee, representatives from the emergent fourth sector.

13. Technology supported and AI-aided
- Use PBL experiences to keep engineering programmes up to date with *avant-garde* technologies.
- Explore the potential of artificial intelligence (AI) in different sectors through PBL and, hence, educate a generation of engineers capable of ethically mentoring AI-related advances in the future.

14. Oriented to lifelong learning
- During effective PBL experiences, students learn to learn, which prepares them for lifelong learning.
- Stimulate students to go beyond course contents and to autonomously learn, in connection with their projects, through participation in external seminars, webinars, MOOCs…

15. Enjoyable (learning through play)
- Make PBL experiences enjoyable, dedicate time to celebrating learning and fostering creativity.
- Design PBL so that students play the leading role and enjoy the process of becoming engineers.

16. Equitable (engineering education for all)
- Select students on the basis of merit and apply PBL to work against any kind of discrimination.
- Spread successful PBL experiences by applying the "MOOC" concept and make PBL reach everywhere and everywhen (i.e. remote regions, LMI settings) for fostering learning on demand for all.

Figure 2.
Summary of good practices for incorporating the key features of Engineering Education 5.0 to modern PBL.

experiences and degrees. A combination of basic and specialization modules can foster fruitful adaptation of PBL to a wide set of programmes.

Other interesting good practices deal with making PBL more holistic, taking inspiration from the engineers of the Renaissance, putting ethics in the foreground, better synergizing with key stakeholders and society, increasing societal impacts and making education more equitable. The hybridization of project-based learning and service learning [17], intensive use of e-Twinning and e-/b-/m-learning methods for supporting an affordable internationalization and for taking benefit from diversity [18], the employment of artificial intelligence tools for supporting educational practice [19] or resorting to open-source software and hardware resources [20], are also relevant strategies with synergic effects.

Ideally, through their projects, students learn how to transform society taking benefit from the ongoing technological revolutions and focusing on real needs and unsolved or partially solved societal problems. During the process, they learn to learn, feel more responsible for their learning, take decisions along a plethora of elective PBL experiences, which helps to personalize education, communicate and celebrate their results, and enjoy the process of becoming engineers. Sharing of methods and experiences, in the project-based learning field, is also fundamental towards high-quality engineering education for all.

3. Implementing PBL in Engineering Education 5.0 programmes

3.1 Synergic integration of PBL within innovative engineering studies

The structures and contents of Engineering programmes in the 5.0 paradigm will necessarily suffer important transformations. A proposal for a universal engineering programme structure, considering contemporary and future engineering roles, has been recently detailed [9]. To summarizing, a whole 6-year programme, integrating a 4-year bachelor's degree plus a 2-year master's degree, can very adequately provide students with fundamental scientific-technological knowledge, specialized professional and transversal skills, necessary ethical values, and even give them important opportunities for personalization and professional planning. This can be achieved through modularity, through collaboration with other programmes, universities and institutions, through the promotion of international mobility and external internships and through a more flexible understanding of all the possible types of experiences that contribute to a holistic training of engineers, as already explained [9].

Let us consider the CDIO initiative, probably the most transformative and international action in the engineering education of the twenty-first century, and the current version of the CDIO standards (version 3.0) [21]. CDIO (from conceive-design-implement-operate) relies on the wise application of PBL principles for making engineering education more effective, through the engineering of different products, processes, and systems. Usually, CDIO-inspired engineering programmes benefit from at least one intensive hands-on or PBL course per training year, and the curricula are methodically designed *with an explicit plan to integrate personal and interpersonal skills, and product, process, system, and service building skills*.

In the author's belief, engineering studies in the 5.0 paradigm should rely on project-based methods even more than in current CDIO-inspired programmes. The use of PBL, not only as a methodology for fostering the ABET professional skills [22, 23], but also for delivering purposeful and continuously updated content, linked to the scientific-technological fundamentals of Industry 4.0 and 5.0, may prove strategic.

Accordingly, this section proposes a general plan for the synergic integration of PBL within engineering studies. The plan incorporates at least one intensive hands-on or PBL course or highly formative student-centered experience per semester, as schematically shown in **Table 1** and further described in **Table 2**.

Different types of project-based activities are considered, all of them relevant and mutually supportive, from the more straightforward and descriptive, to the more complex and integrative. These are classified with some parallelism to Bloom's taxonomy, starting with descriptive and analytical PBL experiences, following with synthetic PBL experiences, and ending up with complete CDIO approaches and final theses. There is also space for local and international competitions, as a way for promoting personalization, for more easily adapting the engineering programmes to relevant engineering trends and for promoting peer learning approaches, in a way bringing *Montessorian* style to higher education. The possibility of linking PBL experiences with R&D tasks, both within universities' departments and laboratories and within research centers and enterprises, reinforces the necessary focus on lifelong learning and the rewarding connection of engineering programmes with the industrial environment. The inclusion of at least one service-learning experience, in the general structure, supports students' orientation to real societal challenges and may stress the fundamental ethical aspects and implications of science and technology. Again, it is necessary to highlight that the varied plethora of PBL initiatives can be an excellent way of helping students follow their paths.

The above-proposed mapping of PBL initiatives along an integral 6-year Bachelor's and Master's Degree in Engineering for Society 5.0 can be adapted to any engineering programme of the 5.0 paradigm. The initial PBL experiences (years 1st–2nd) have a clear focus on knowledge acquisition and concentrate on the promotion of analytical skills, while those from the 3rd to 6th years are directed towards knowledge application and foster more technical and professional skills.

Countless examples can be provided for each type of PBL experience and **Table 2** just aims at providing a brief description, of the different types of modern PBL experiences, and some implementation examples in the context of Engineering Education 5.0. Many of the cited examples apply the techniques

Programme level	**Academic year**	**First semester experiences**		**Second semester experiences**		**Total PBL credits/year**
		Type of PBL experience	**PBL credits**	**Type of PBL experience**	**PBL credits**	
Master's Degree in Engineering for Society 5.0 (120 ECTS)	6th	R&D PBL	6	Final degree thesis	12	18
	5th	CDIO PBL	6	In-company PBL	6	12
Bachelor's Degree in Engineering for Society 5.0 (240 ECTS)	4th	CDIO PBL	6	Final degree thesis	12	18
	3rd	Synthetic PBL	6	International competition	6	12
	2nd	Analytical PBL	3	Service-learning experience	6	9
	1st	Descriptive PBL	3	Local competition	3	6

Table 1.
Proposal for mapping different types of PBL initiatives along with an integral 6-year Bachelor's and Master's Degree in Engineering for Society 5.0.

Types of PBL experiences	Description	Implementation examples
Final degree thesis	Holistic and highly integrative PBL experience, in which students, normally on their own and supported by a mentor, design de novo an engineering solution or optimize an existing product or system.	• Develop a lightweight structure. • Optimize a system's eco-impacts. • Design a vehicle suspension.
R&D PBL	In-depth study of a specific problem, within an ongoing R&D project of a university department and supporting project's team. As in capstone projects, a paper based on results may be written as a conclusion.	• Design a biomedical MEMS. • Develop an AI-aided device. • Research an innovative material.
In-company PBL	Immersive industrial experience, through which students live a professional practice helping to solve a real problem or trying to optimize a company's processes, products, or solutions.	• Enhance a production line. • Select subsystems for a new plant. • Help with a marketing strategy.
CDIO PBL	Highly integrative PBL experiences, in which students' groups live through the complete conceive-design-implement-operate cycle of innovative engineering products, processes or systems.	• Design & build a medical device. • Prototype a 3D printing machine. • Create a pump for remote regions.
Synthetic PBL	PBL experiences focused on reaching a solution proposal for an engineering problem. Typically, students detect a need, develop a concept, and reach a design of an engineering product, process, or system.	• Design a specified gearbox. • Define the layout of a factory. • Model an eco-house.
Analytical PBL	PBL experiences focused on the study of an existing engineering system, which is normally divided into subsystems and components for understanding and modeling its functional principles and behaviour.	• Simulate a production chain. • Model robotic arm kinematics. • Reverse engineer a solar panel.
Descriptive PBL	PBL experiences, in which students, in some cases following a case study approach, describe a relevant need and existing solutions, documenting one of the possible solutions in detail.	• Select and describe a machine. • Document a factory's subsystems. • List down materials of a satellite.
Service-learning experience	Formative experiences with a clear social purpose, in which students are connected to a real societal problem and asked to provide an engineering-related solution after interaction with key stakeholders.	• Design campus recycling strategy. • Organize a social fundraising fair. • Conceive a purposeful network.
International competition	Like the local competitions, but international and normally involving more challenging problems and requiring the delivery of a final product prototype-.	• Formula SAE/Student. • Solar Decathlon. • Robot design competitions.
Local competition	Focused design competitions, usually for first-year students and with a socialization purpose, together with the formative objective, in which teams provide engineering solutions to open-ended questions.	• Creativity weeks/challenges. • App design competition. • Applied maths hackathons.

Table 2.
Description and implementation examples of modern PBL experiences in the Engineering Education 5.0 paradigm.

from Industry 4.0 and 5.0, like artificial intelligence, big data, internet of things, cyberphysical interfaces, multi-physical/chemical simulations, digital twins, additive manufacturing, collaborative robots, autonomous systems ..., to solving problems in different industries and engineering fields. In other cases, the PBL

	Students' outcomes as proposed by ABET										
Types of PBL experiences	**a. an ability to apply knowledge of mathematics, science and engineering**	**b. an ability to design and conduct experiments and analyze data**	**c. an ability to design a system or component to meet specifications**	**d. an ability to function on multidisciplinary teams**	**e. an ability to identify, formulate and solve engineering problems**	**f. an understanding of professional and ethical responsibility**	**g. an ability to communicate effectively**	**h. a broad education to understand the impact of engineering solutions**	**i. a recognition of the need for and an ability to engage with lifelong learning**	**j. a knowledge of contemporary issues**	**k. an ability to use the techniques, skills and tools for engineering practice**
Final degree thesis	XX	X	X		XX	X	X	X	X	X	X
R&D PBL	X	XX	X		X			X	X	X	X
In-company PBL	X			X	X	X	X	X	XX	X	X
CDIO PBL	X	X	XX	X	X	X	X	XX	X	X	X
Synthetic PBL	X		X		X	X					XX
Analytical PBL	XX	X						X			X
Descriptive PBL	X						X			XX	
Service-learning experience	X			X	X	XX	X	X		X	
International competition	X			XX			X				X
Local competition	X			X			XX				X

Table 3.
Different types of PBL experiences and their connections with students' outcomes, employing the ABET professional skills as reference.

initiatives are focused on designing or further developing such technologies. The redesign or reengineering of existing products, processes or systems, with sustainability principles in mind, can be also a source for highly rewarding PBL experiences, in connection with all Sustainable Development Goals.

Pioneering experiences in the PBL arena will, of course, continue enlightening the new generations of engineers. Among them, it is important to mention: the "Formula SAE/Student" automotive challenges (dating back to 1981), the "IARC" competition on aerial robotics (since 1991), the "CAN-SAT" satellite construction challenges (since 1998), the "FIRST Lego League" robotics competitions (since 1998), the "Solar Decathlon" competitions focused on efficient buildings (since 2002), the James Dyson Design Competitions (since 2007) and the "UBORA" medical device design schools (since 2017), to cite some examples in varied engineering fields. Most of them have taken benefit from the methods and techniques from Industry 4.0 and 5.0, well before the coining of such terms, and have also helped to research and develop several working methods and technologies that are central to current industrial revolutions.

3.2 Systematic promotion of students' outcomes through modern PBL

The previous section has mapped the different types of PBL experiences along with an integral 6-year Bachelor's and Master's Degree in Engineering for Society 5.0, as an example of how any engineering programme may be transformed through truly transformative student-centered activities. Now, it is also necessary to integrate these experiences in a synergic or mutually supportive way, to systematically promote students' outcomes.

Employing the ABET professional skills as a reference, **Table 3** presents an example of how different types of PBL experiences connect with students' outcomes, considering that each outcome should be specifically covered by at least one PBL experience of the engineering programme (see also **Table 2**). The more integrative PBL experiences (final theses, R&D PBL and CDIO experiences), for instance, may well synergize for fostering students' abilities to apply knowledge from maths, science and engineering, to identify, formulate and solve engineering problems, to design systems and components to meet specifications and to understand the impacts of engineering solutions. Other more focused PBL experiences (in-company PBL, competitions, analytical/synthetic) may promote ABET's skills d, f, g, i, j, k.

4. From Industry 4.0 to Society 5.0 through modern PBL

4.1 Advancing technologies from Industry 4.0 towards Society 5.0

Once explained how different types of PBL experiences may be mapped along a universal 6-year engineering programme for Society 5.0 and how the different kinds of experiences support each other for the promotion of students outcomes, this section concentrates on how PBL may help to further develop the technologies from Industry 4.0 towards Society 5.0, considering also the roles of modern engineering professional practice and providing an application example of how PBL may vertebrate a specific engineering programme for Society 5.0. **Table 4** presents several examples of PBL teaching-learning experiences for deploying the technologies from Industry 4.0 and hence constructing Society 5.0. Depending on the outcomes and industrial area of the specific engineering programme and on students' wishes a myriad of combinations is possible.

	Key topics	Possible PBL teaching-learning experiences for deploying Industry 4.0 and constructing Society 5.0	Types of PBL experiences
Technologies from the Industry 4.0 paradigm	Artificial intelligence	• Prototype a skin cancer diagnostic app. • Describe and discuss AI-related ethical issues.	• Competition/ CDIO-PBL. • Descriptive PBL.
	Big data	• Develop and test a pandemic simulator. • Develop a predictor for environmental collapse.	• Synthetic/CDIO-PBL. • Synthetic/CDIO-PBL.
	Smart factories	• Implement a quality control artificial vision. • Reengineer a production unit using a digital-twin.	• In-company/ CDIO-PBL. • In-company/ CDIO-PBL
	Autonomous robots	• Design soft robot swarms for space colonization. • Train a drone for fragile parcel delivery.	• R&D PBL. • Competition/ CDIO-PBL.
	3D printing & flexible production	• Redesign a car's chassis oriented to 3D printing. • Create an innovative metamaterial by 3D printing.	• Final degree thesis. • R&D PBL.
	Internet of things	• Design and construct a smart mini-bar for hotels. • Develop wearable sensors for Alzheimer's control.	• CDIO-PBL. • Service learning.
	Cybersecurity	• Cybersecurity and privacy issues in smart cities • Map & model a company's cybersecurity threats.	• Descriptive PBL. • Analytical PBL.
Expected transformations within Society 5.0	Sustainable mobility	• Create an app for reduced mobility persons. • Implement an app for predicting traffic jams.	• Service learning. • Competition/ CDIO-PBL.
	Better health management	• Design and prototype a health monitoring shirt. • Develop a medical passport app.	• Synthetic/CDIO-PBL. • Final degree thesis.
	Customized products	• Create an app for eyewear mass customization. • Design and prototype a personalized prosthesis.	• In-company/ CDIO-PBL. • Final degree thesis.
	Reformed organizations	• Analyze and model the processes of a company. • Reengineer a hospital's emergency unit processes.	• Analytical PBL. • In-company PBL.
	Improved services	• Design an AI-tool for supporting career planning. • Develop an app for supporting exchange students.	• Service learning. • Service learning.
	Smart cities & environments	• Model the security processes of a smart building. • Model the autonomous operation of a whole city.	• Analytical PBL. • Analytical PBL.

Table 4.
Examples of PBL teaching-learning experiences for deploying the technologies from Industry 4.0 and hence constructing Society 5.0.

4.2 PBL oriented to the professional engineering roles in Society 5.0

Besides, the increasing connection between engineering disciplines may contribute to a progressive dissolution of borders between the classical specializations of the programmes of studies. Probably, structuring Engineering Education 5.0 programmes according to the modern professional roles of engineers, which are more stable than the continuously evolving and nascent engineering majors, may be an adequate solution for constructing universal engineering programmes [9]. With this perspective, **Table 5** describes and exemplifies PBL oriented to the different professional engineering roles in Society 5.0.

4.3 Example: PBL in a Biomedical Engineering 5.0 programme

Considering all previous sections, **Table 6** presents the concrete mapping of modern PBL experiences throughout an integral 6-year Bachelor's and Master's Degree in Biomedical Engineering for Society 5.0. In the scheme, all types of PBL experiences synergize for providing students with basic and applied knowledge, for letting them acquire technical and professional skills, liked to most areas of Industry 4.0 and several challenges of healthcare within Society 5.0.

4.4 Discussion and future implementation pathways

The presented perspective is based on an analysis of the recent evolution of PBL-experiences and engineering education, in general, and follows the findings and continuation proposals of transformative educational experiences described in the selected references. However, it also derives from the author's personal and highly rewarding experiences in the design and implementation of different kinds of PBL experiences in six different degrees of studies at UPM, carried out at bachelor's, master's and doctoral levels, as well as in international onsite and online hackathons, bootcamps and engineering design schools.

Some of these successful stories, in connection with different types of PBL experiences already including some features of Engineering Education 5.0, have been previously reported [15, 19, 20, 24]. Nevertheless, the creation of a whole 6-year engineering programme, completely structured around PBL experiences focusing on the technologies from Industry 5.0, as schematically presented in **Tables 1** and **6**, is still an educational dream. The author intends to progress towards the implementation of this kind of educational model, which connects with the pioneering example and aims of the International CDIO Initiative, perhaps taken to the extreme, until its last consequences and interwoven with continuously evolving technologies, which requires more dynamic programmes.

Such real-life implementation can follow differently and mutually supporting strategies. A first and straightforward strategy could rely on the gathering of successful PBL experiences, across programmes of a university, and on letting students select (initially as one or two electives per year), those more in line with their interests. A second strategy, now that inter-university campuses are being created across Europe (Erasmus+ European Universities programme), would be to organize biannual international PBL events within these new communities, offering different types of PBL experiences related to Industry 5.0 and with a common credit transfer system. This would also help to vertebrate the new European universities. A third option would be to update the contents and methods of already existing engineering programmes and transform them through modern PBL. To this end, the bottom-up changes introduced by professors, already carrying out transformative PBL in their courses, can act as seminal examples. Finally, a fourth alternative is

Modern engineering professional roles	**Description of PBL experiences and features oriented to the different roles**	**Possible implementation examples**
1. Products, processes, and systems engineers	Students live through the specification, conception, design, prototyping and testing of innovative products, processes, or systems, usually employing CAD-CAE-CAM programs and AM technologies and rapid prototyping tools as resources.	• CDIO PBL of an innovative product. • CDIO PBL of an innovative process. • Development of robots, vehicles, satellites, machines, chemical reactors, building models, apps, simulators…
2. Management and business engineers	Students live through the strategic planning of an enterprise and develop its business model or help to reengineer processes within existing industrial plants.	• Create a business plan for a product. • Set down the foundations of a spin-off. • Design a commercialization strategy. • Reengineer a factory's processes.
3. Scientific and research-oriented engineers	Students experience a research project, generally working within a university department or research center, working on basic or applied research tasks, solving a specific problem, and publishing a paper.	• Characterize & model a smart material. • Simulate a nanoparticle cancer therapy. • Optimize a plasma deposition system. • Prepare an experimental process.
4. Political engineers and regulators	Students understand the key relevance of standards, regulations, and policies for enabling technologies to reach those needing them most safely and effectively.	• Design a machine for CE marking. • Design a biodevice under a standard. • Investigate a system's safety. • Create a policy making working group.
5. Social and humanistic engineers	Students supervise the ethical implications of an innovative technology and promote human-centered design processes, working towards optimal societal impacts.	• Optimize a design for better usability. • Study the ethical issues of technology. • Evaluate a system's human impacts. • Study the viability of a social enterprise.
6. Media & arts and cultural engineers	Students experience and foster innovative connections between engineering and art by conceiving, designing, and developing new materials, designs, processes, and methods.	• R&D of CAD/AMT applications for art. • Define a heritage management strategy. • Apply new materials to the textile industry. • Organize an exhibition or performance.
7. Environmental and urban planning engineers	Students focus on human environments focusing on well-being and living through projects linked to improving buildings, cities, and communities in general.	• Intelligently document a building. • Restore creatively an ancient building. • Define a city's environmental strategy. • Conceive the layout for a new city.
8. Biomedical and biological systems engineers	Students design and develop technologies and processes in connection with the biomedical field and with biological systems and biotechnology in general.	• CDIO PBL of a medical device. • R&D of bio-MEMS for diagnosis. • Optimize a hospital's processes. • Design of a biorecycling facility.

Table 5.
Description of PBL experiences oriented to the different professional engineering roles in Society 5.0.

foreseen: evolving already existing PBL courses towards the concept and context of Engineering Education 5.0 (dynamically updating and incorporating new technologies, making knowledge-based and outcomes-based education compatible, focusing on the SDGs and sustainability, taking account for the human and ethical aspects of engineering, among others).

Programme level	Academic year	First semester experiences		Second semester experiences		Total PBL credits/ year
		Type of PBL experience	PBL credits	Type of PBL experience	PBL credits	
Master's Degree in Biomedical Engineering for Society 5.0 (120 ECTS)	6th	R&D PBL: Hands-on experience linked to the development of innovative tissue engineering and biofabrication solutions	6	Final MSc thesis: Develop a medical technology and set the foundations for a related spin-off company	12	18
	5th	CDIO PBL: Design and prototyping of an IoT device for health management	6	In-company PBL: Participate in the QA/QC of production and supply chain of a medical product	6	12
Bachelor's Degree in Biomedical Engineering for Society 5.0 (240 ECTS)	4th	CDIO PBL: Design and prototyping of an AI-based diagnostic device	6	Final BSc thesis: Develop an app benefiting from big data for health prognosis	12	18
	3rd	Synthetic PBL: Design, simulate and 3D print a personalized medical device	6	International competition: Participation in an "UBORA" competition and design school [24]	6	12
	2nd	Analytical PBL: Select a relevant medical device, check applicable standards for its safe development and propose a regulatory pathway towards commercialization	3	Service-learning experience: Select a hospital process, study it and propose improvements by collaborating with healthcare professionals	6	9
	1st	Descriptive PBL: Map biomedical technologies in connection with Industry 4.0 tools and the Society 5.0 paradigm	3	Local competition: Ideas challenge for approaching the "healthcare of the future"	3	6

Table 6.
Implementation example: concrete mapping of modern PBL experiences throughout an integral 6-year Bachelor's and Master's Degree in Biomedical Engineering for Society 5.0.

Top-down approaches and decisions might also support these directions and offer change in the mid-term future. One could foresee international accreditation agencies assuming these principles along the current decade, or a rectorate deciding to update the educational model of a whole university, which could be built around PBL and Industry 5.0. Despite these top-down possibilities, in the author's view, the more relevant educational changes at universities tend to follow bottom-up schemes, starting with an inspiring conversation in the classroom between students and professors or with a shared dream among colleagues from a department or faculty, which act as the crystallization seeds of change.

Accordingly, to favour the proposed transition towards PBL 5.0, the following scheme of **Figure 3** provides a guided set of steps and driving questions, through which PBL for Industry 5.0 experiences can be designed, managed and evaluated,

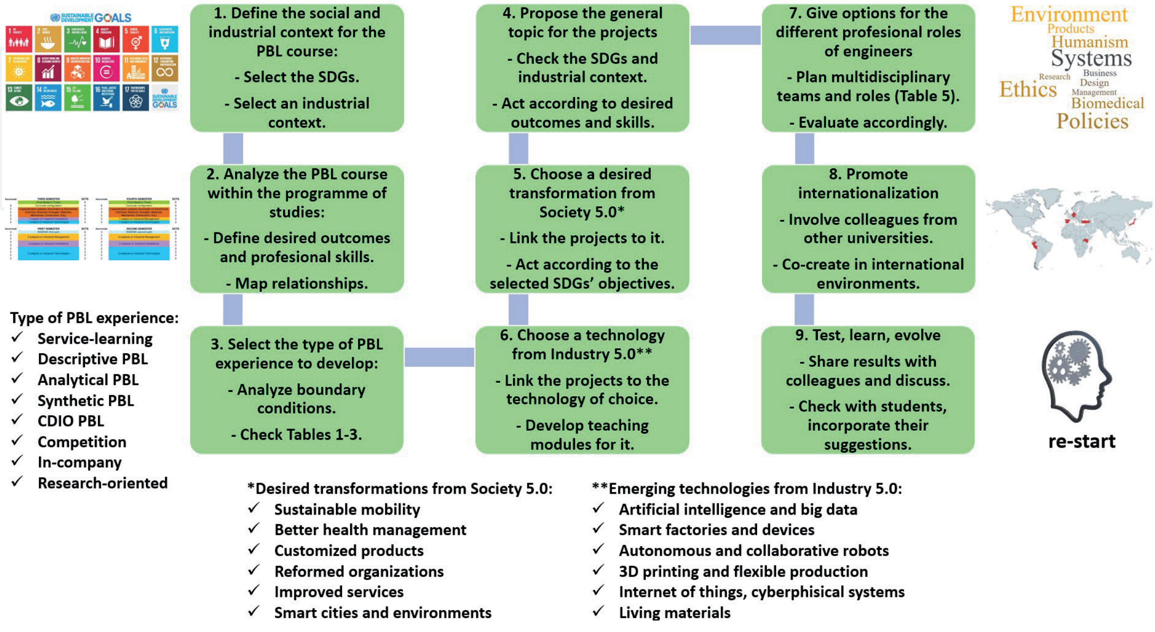

Figure 3.
Guided steps and driving issues for creating PBL 5.0 experiences.

Figure 4.
(a) Upper images: relaxed discussions and peer learning in international PBL experiences. (b) Lower images: PBL prototyping results of biodevices for good health and well-being (SDG3). Innovative Braille display, testing a 3D printed water filter, and face-protecting splints for safe sport practice. Courtesy of UBORA project.

with a focus on their steady integration in already existing engineering programmes, for acting as the previously cited seeds of change. Additional advice may be found in recent publications [25, 26].

Finally, **Figure 4** presents some examples of typical behaviours (students and professors learning together, more Socratic discussions than master classes), environments (international teams, tinkering possibilities, onsite and online interactions), and results (real working prototypes solving relevant needs) expectable in PBL 5.0 experiences mentored by the author.

5. Conclusions

Times are changing in engineering education, as a consequence of the current non-stop concatenation of scientific-technical breakthroughs and related technological revolutions. The age of untouchable decades-lasting engineering programmes is over, and dynamism, evolution, flexibility, and equity are paramount to modern engineering education. In a personal definition, modern engineering may correspond to *the development and application of scientific and technical knowledge to the discovery, creation and mentoring of technologies, capable of transforming human societies and environments, for increased well-being and life quality and, hence, necessarily following sustainability and equity principles*.

In consequence, strategies for enabling the continuous improvement and adjustment of engineering programmes, in a world of changing boundary conditions, are needed. To this end, PBL methodologies and experiences may vertebrate or serve as a scaffold for constructing the engineering programs in the Education 5.0 paradigm. This has been discussed and supported with varied implementation examples and methods, for the successful integration of PBL within modern engineering curricula. In this new context, PBL methodologies are not only hands-on activities for knowledge application, but play also an essential role, within the global educational strategy, for delivering purposeful and continuously updated content, for knowledge acquisition and for developing descriptive, analytical, synthetic, technical and personal skills.

Conflict of interest

The author declares no conflict of interest.

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