Transdisciplinarity in a bio-engineering course

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Abstract

In order to face environmental issues related to resource management and the protection of our ecosystems, future engineers must be aware of the need to develop new sustainable technologies.

Our multidisciplinary and transdisciplinary course aims at sensitizing students to the major challenges related to the environment and resources. In particular, bio-engineering for the production of biosourced and biodegradable polymer materials, waste treatment and recovery, as well as ecosystems remediation are addressed.

The aim of the lectures, in the first part of the course, is to introduce notions of ecology, biotechnology, polymer materials and process engineering, in order to prepare the project part which allows students to develop achievements on bio-based materials.

The students choose from four project areas: the design and construction of a biodegradation reactor, the production of enzymes by genetic modification of bacterial strains, the implementation and optimization of biodegradation processes, the development and transformation of polymer materials, in particular bio-based and biodegradable materials.

Finally, students are invited to consider the importance of interactions between complementary disciplines for the success of sustainable and responsible complex projects such as those in the field of bio-engineering.

Key words: Ecology, Bio-based polymers; Enzymes, Biodegradation; Process engineering; Human Sciences.

1. Introduction

With the growing expectations of consumers for taking environmental dimensions, it is a real challenge for the future of certain value chains to integrate environmental challenges but also to add a societal dimension to the CSR framework (Corporate Social Responsibility, ISO 26,000).

The value chain of polymers and products containing plastics presents major challenges both from a regulatory point of view (recycling rate to be achieved), from environmental perspectives (impacts on resources, pollution of the oceans), from societal (health impacts, jobs related to plastics) and technical (essential materials in certain applications) viewpoints. Research projects related to the development of alternative solutions for polymers (biosourced) and chemical recycling are expanding. It is therefore essential to ensure that the directions taken from environmental and societal points of view will be economically sustainable and will have positive impacts as the changes imposed on the polymer value chain are important and complex.

In this context, in order to face environmental issues related to resources management and the protection of our ecosystems, future engineers must be aware of the need to develop new sustainable materials and technologies. As L. Ablin [Ablin, 2018], our course aims at engaging students with the complexity of the real world by a transdisciplinary approach [Tejedor, 2018]. It is necessary to find the conditions required, both socio-economic and in the field of materials science, allowing biosourced polymers to position themselves sustainably alongside conventional polymers. It is therefore essential to combine economic aspects (innovation economy, industrial economy, ecological economy, circular economy) with innovation resulting from the Material Design to bring about relevant solutions that can spread massively.

The interdisciplinary course we manage, aims at studying both engineering and societal challenges that should permit biosourced polymer materials to be able to i) integrate a circular economy or ii) undergo enhanced assimilation if unfortunately dispersed in natural media. Indeed, our present society model overexploits critical resources, which impones a transition towards a circularity that is an European priority, associated with societal responsibility as well as environment protection. Unfortunately, part of polymer or plastic materials are dispersed in the environment, in which they can remain for tens of years, due to their stability. As an example, rivers and oceans are polluted by macro and micro plastics. Enhanced management of waste should be a way to reduce this pollution, but it might not be sufficient. Indeed, microplastics are produced by the inevitable abrasion of tyres, textiles... In this context, biodegradable polymer materials might be an interesting alternative to conventional non biodegradable materials, poorly assimilated in the environment.

From this point of view, students are invited to study several parts of the life cycle of recyclable, bio-sourced and biodegradable materials as well as to discuss on their societal interests. Recyclable, bio-based and bio-degradable materials represent a challenge for both engineering and societal sciences and it seems mandatory to associate ‘Material Design’ [Lins 2015, Livi 2015] with societal questions.

The objective of the course is to eco-design eco-friendly polymer materials [Quitadamo. 2018, Delamarche 2020a, 2020b] with ability for hydrolysis by enzyme catalysis as well as for biodegradation to make future engineers able to contribute to the sustainable development goals SDGs 9 & 12 of the United Nations that intend to establish « resilient infrastructure », as well as to promote a « sustainable industrialisation » “benefitting all and encouraging innovation as well as implementation of a responsible consumption and production”. In parallel, societal impacts of those new bio-based materials are debated.

2. Structuration of the core courses

Figure 1 displays the contributions of each discipline of the core courses and projects as well as their interactions in order to design environment friendly polymer materials. Courses deal with the management of resources and energy (depletion, dispersion), protection & decontamination of media & ecosystems, eco-compatible design (valorisation of waste), biotechnologies & polymer materials (life cycle, biodegradability), development of sustainable technologies for human being & environment. Societal challenges are discussed in a transverse way with points of view of human, life and material sciences. For example, circular economy and recycling imply not only technological innovation but also behavioral adaptations of the consumers for ensuring quality of the collect and thus of the future recycled materials. Social acceptability as well as the image of recycled materials have also to be addressed. As the price of recycled bio-based polymer materials cannot exceed the one of virgin ones, that are only of a few euros per kg, recycling costs have to be low. Objects designed for easy disassembling can also offer great interest. Thus, it is important that engineer students be conscious of the socio economical constraints associated with the development of new materials and objects. They have to consider those latter as well as the associated constraints for the design of both materials and objects.

Below is the courses list.

Ecology and environment sciences: knowledge, skills in ecology and ecosystems, environmental challenges of anthroposystems development, methods & tools for the sustainable management of anthroposystems.

Experimental enzymology: enzyme kinetics.

Biotechnology of DNA: genes and genome, genes expression and regulation, basics of synthetic biology, extraction of DNA.

Materials science for biosourced polymer materials: organic chemistry, basics on polymers, biosourced structures and properties, polymer processing, polymer materials & environment, study of mechanical & physico-chemical properties.

Process & chemical engineering for the modelisation of a bioreactor: chemical kinetics, reaction engineering, enzymology, growth models (introduction to ordinary 1-dimensional differential equations), chemostat model (introduction to dynamic 2-dimensional systems), inferential statistics (linear and non-linear adjustment of the Michaelis-Menten model).

Enzyme behaviour modelling: numerical simulation (Matlab) and self-centered programming (Python)

Human sciences: concept of technical culture, mode of existence of technical objects, invention and innovation, frugal innovation, waste management, innovation and sustainable development, imaginary and biotechnologies, major ethical issues of biotechnology and patentability of life, responsibility of the engineer.

Documentary research: Identification of information sources, research methodology, intellectual property, project monitoring.

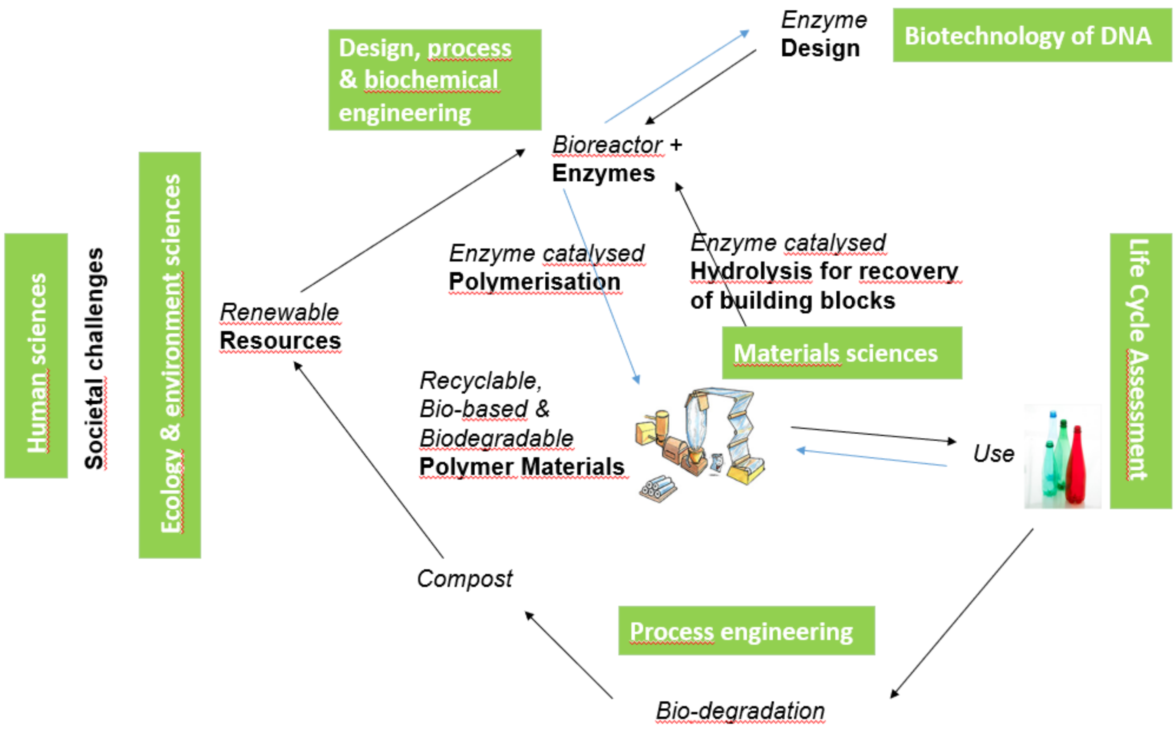

Figure 1: potential interactions and contributions of fields of study for a circularity of environment responsible bio-based polymers.

3. Complementary projects

In addition to the core courses, each student has to perform one out of four complementary engineering projects. In parallel, students are invited to discuss on innovation, ethics, responsibility of the engineers that are associated with the societal challenges of the course. Concerning the societal challenges, the students write an article on a topic related to their own project, the current state of society and the planet [Omotola, 2018]. This is an opportunity to think about the evolution of science and technology in relation to the preservation of our resources, ecosystems and humanity.

For the engineering part, the four complementary projects, at different stages of the life cycle, are described below.

Process Engineering Project. Materials Environmental Behaviour: this project deals with both the aerobic and anaerobic biodegradability as well as bio-treatment tests in pilot reactors.

Design - Manufacturing: Development of a fermentor for biodegradation of a bio-sourced polymer material. Design of fermentors such as respirometers, methanizers.

Synthetic biology, genetic modification of Escherichia coli and production of an enzyme for biodegradation: catalysis, design of new genetically modified (GM) bacterial strains to degrade biomaterials or design new ones, modelling of the functioning of an enzyme, analysis *in silico* of the α-amylase gene.

Biosourced polymer materials: Development and transformation of a biosourced polymer material for fabrication and characterizations (mechanical and physicochemical properties) of objects such as meal trays, signaling tape, parachutes, plastic bags… Life Cycle Analysis (LCA) of paper and plastic packagings.

As depicted in Figure 1, in our interdisciplinary and transverse approach, the courses described above are used for thinking about a circularity of environment responsible bio-based polymers. In this perspective, the materials engineering component will aim to eco-design biosourced polymer materials with improved performances and differentiating characteristics in order to offer a great versatility of properties with an ability for material or organic (biodegradation in a compost, soil...) recycling. This scientific challenge implies, at the same time, a social analysis to identify the technological and socio-economic barriers related to the conditions of uses, and recycling of bio-sourced polymers that are essential for the deployment of a circular economy of these materials. As explained above, the success of circularity should be facilitated by anticipating the end-of-life when designing materials and objects, economically sustainable. It is ever known that "multi layered multi-materials", that offer good gas barrier properties interesting for packaging applications are not easy to recycle. An alternative is to develop "multi layered mono-materials", that may present different properties. Both the quality and quantity of waste collection are also key parameters for facilitating circular economy. It is important to understand how to increase them with deployment of economically sustainable technologies as well as the evolution of consumers behaviours. Quality should stimulate demand and acceptability of recycled materials. In this perspective, technological developments, communication as well as the image of the recycled materials could be considered in parallel.

Combining all the courses, complementary projects and working on inter-disciplinary interfaces, should give students the means to solve at least part of the very multidisciplinary issue related to the development of a circular economy of bio-based polymers.
The production of complementary knowledge related to Materials Science, Human and Social Sciences and at the interface between them, should contribute to the United Nations Sustainable Development Goals (SDGs) 9 and 12.

4. Conclusion & perspectives

The emergence of a circular economy of bio-based materials requires the lifting of not only technological but also socio-economic barriers. If the development of breakthrough innovations in chemistry and materials science is a first condition, the massive diffusion of these innovations in society requires a fine analysis of the value chains of the actors involved in the production and recycling of polymers. The interest of the course lies in its ability to mobilize the complementary and necessary skills for the analysis of these different locks and their interactions.

In this regard, students are invited to consider the importance of interactions between complementary disciplines for the success of sustainable and responsible complex projects such as those in the field of bio-engineering.

Students become aware that some answers can only be generated by working on inter-disciplinary interfaces. The initiation to research gives the means to solve at least part of the very multidisciplinary challenge of developing bio-sourced, recyclable and biodegradable materials with consideration of societal challenges.

As a perspective, integrating a depolymerization enzyme catalyst into a biosourced polymer as soon as the polymer is designed and activating the depolymerization agent under the effect of a stimulus (heat, light, etc.) would permit to go a step ahead.
As another perspective, we should also consider that the emergence of a circular economy of bio-based materials requires the evolution of not only technological but also socio-economic barriers, such as deployment of economically sustainable technologies, evolution of the consumers behaviours as well image of the recycled materials. In this regard, it might be relevant to develop deeper socio-economic analyses to inform and guide research planning.

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