

Collaborative Learning with Sustainability-driven Projects: A Summary of the EPS@ISEP Programme

<https://doi.org/10.3991/ijep.v8i4.8260>

Manuel F. Silva^(✉), Benedita Malheiro, Pedro Guedes, Abel Duarte, Paulo Ferreira
Porto Polytechnic, Porto, Portugal
mss@isep.ipp.pt

Abstract—This paper describes the collaborative learning environment, aligned with the United Nations Millennium Development Goals, provided by the European Project Semester (EPS). EPS is a one semester capstone project programme offered by eighteen European engineering schools as part of their student exchange programme portfolio. In this international programme, students are organized in teams, grouping individuals from diverse academic backgrounds and nationalities. The teams, after choosing a project proposal, become fully responsible for the conduction of their projects. By default, project proposals refer to open multidisciplinary real problems. The purpose of the project is to expose students to problems of a greater dimension and complexity than those faced throughout the degree programme as well as to put them in contact with the so-called real world, in opposition to the academic world. EPS provides an integrated framework for undertaking capstone projects, which is focused on multicultural and multidisciplinary teamwork, communication, problem-solving, creativity, leadership, entrepreneurship, ethical reasoning and global contextual analysis. Specifically, the design and development of sustainable systems for growing food allow students not only to reach the described objectives, but to foster sustainable development practices. As a result, we recommend the adoption of this category of projects within EPS for the benefit of engineering students and of the society as a whole.

Keywords—collaborative learning, project-based learning, engineering education, sustainability, aquaponics, escargots, insects

1 Introduction

Collaborative learning is an exercise in the field of knowledge construction (the most used terms in English are teaching and learning) that is based on the acquisition of knowledge by two or more autonomous and independent individuals, through sharing of ideas, and who are willing to learn and work together [1].

Humanitarian and environmental sensitivity are preponderant factors in terms of engineering decision making. The engineering profession, which is governed by a professional code of ethics, is driven by the improvement of the well-being of the humanity. As such, all engineering activities must be sustainable. This type of consciousness / knowledge is widely disseminated in the practice of collaborative learn-

ing since knowledge emerges within working groups, fruit of the individual sensibilities of students.

The European Project Semester (EPS) is a one semester student-centred and student-led training for engineering design [2]. The students, integrated in small groups of people willing to learn, have the objective of solving a problem, being the solution of the task always multidisciplinary. The collaborative process aims at the fluidity of ideas within the group of different protagonists, learners from different areas of knowledge and coming from very different cultural contexts, capitalizing on individual resources and skills for a final solution. All stakeholders are responsible for project management (identification, planning, and allocation of tasks), finding the solution (duly supported and scientifically justified), selection and specification of the materials and components, as well as later assembly and testing of the prototype to be delivered at the end of the semester. The whole process is monitored and coached during a weekly supervision meeting attended by a group of teachers (the team of supervisors) from different scientific areas who oversees the teamwork.

All projects developed within EPS are based on the application of scientific, economic, social and practical knowledge with the intention of designing and developing goods to improve the quality of life of the human species [3]. It is not rational to have tremendous development and accumulation of wealth in few regions and people, while, simultaneously, a significant part of the human population lives on the threshold of poverty.

Sustainability is based on a simple principle: “Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment.” This simple principle defined by the United States Environmental Protection Agency (EPA) is based on four interrelated axes: environmental responsibility; environmental sustainability; economic viability; and social acceptance [4]. More important than the considerations of governments and policy makers, what each one of the more than 7 billion people in the world does in his/her daily lives will be reflected permanently in the state of the planet today and in the future.

The United Nations, with its 189 member states, defined in September 2000 eight Millennium Development Goals to be achieved by 2015 [5]. The first major objective (Goal One) is: Eradicate extreme poverty and hunger, and, another important one (from the viewpoint of EPS) is Goal Seven: Ensure environmental sustainability. Although far from having been achieved, some positive progress has been made [5].

Moreover, one of the major issues for humanity is the lack of sustainable good quality food sources. The Food and Agriculture Organization (FAO) estimates that the world needs to increase its food production by 70 % by 2050 in order to serve a global population of 9 billion. Furthermore, the standard food production model is unsustainable in terms of resources required (energy, soil, water) and by-products produced (emissions). Research is forcing people to re-think food production and recommending, for instance, the adoption of specific insect species as a higher source of nutrition. Insects form part of the traditional diets of at least 2 billion people, mainly in Asia and Africa. In the remaining world regions, the main use of insects is for animal feeding. More than 1900 species have reportedly been used as human food [6].

This paper reports three projects developed within EPS: *(i)* the aquaponics system, a hybrid system to produce plants and fish in aqueous medium; *(ii)* the insectarium, a domestic system for growing edible insects; and *(iii)* the escargot nursery, a domestic system for growing edible snails.

The remainder of this paper is organized according to the following structure. Section 2 briefly introduces the European Project Semester (EPS) and its implementation at the School of Engineering of the Porto Polytechnic (EPS@ISEP), followed by Section 3 that describes three examples of projects developed in the scope of EPS@ISEP, which are aligned with the UNESCO Millennium Development Goals. Section 4 presents a discussion of the programme implementation and the main results achieved, and the paper finishes with the main conclusions in Section 5.

2 EPS – European Project Semester

2.1 The EPS Programme

The EPS framework is a one semester student-centred international capstone project/internship programme offered to engineering, product design and business undergraduates, designed by Arvid Andersen [7]. EPS started in 1995 in Denmark and is currently offered by a group of 18 European engineering schools, from 12 countries, called the EPS Providers, as part of their student exchange programme portfolio. The goal of the programme is to prepare future engineers to think and act globally, by adopting project-based learning and teamwork methodologies, fostering the development of scientific, technical and soft skills. In particular, multidisciplinary and multicultural collaborative learning and sustainable and ethical development are pervasive concerns within EPS projects. The programme provides an integrated framework to undertake engineering capstone projects supported by a project-based learning methodology. Moreover, it focusses on teamwork and exposes students to cultural, scientific and technical diversity. The EPS package is organised around one central module – the EPS project – and a set of complementary supportive modules. The project proposals should refer to open multidisciplinary real-world problems, empowering the teams for the conduction of their projects [8].

The EPS providers have discussed, agreed upon and posted on the EPS Providers site the specification of the EPS framework – the so-called “10 Golden Rules of EPS” that an EPS provider must comply with: *(i)* English is the working language of EPS; *(ii)* EPS is multinational with a group size of minimum three and maximum six students, being four or five the ideal number; a minimum of three nationalities must be represented in each EPS group; *(iii)* ideally, but not necessarily, an EPS project is multidisciplinary; *(iv)* an EPS semester is a 30 European Credit Transfer Units (ECTU) package, the duration of which is not less than 15 weeks; *(v)* an EPS project has a minimum of 20 ECTU and the complementary subjects account for a minimum of 5 ECTU and a maximum of 10 ECTU; *(vi)* the main focus on EPS is on teamwork; *(vii)* the subjects included in the EPS must be project supportive; English and a basic crash course in the local language must be offered; *(viii)* the subjects must include

Teambuilding in the very beginning and Project Management in the beginning of an EPS semester; (ix) project supervision/coaching must focus on the process as well as the product; and (x) EPS must have continuous assessment including an Interim Report and a Final Report. The different EPS programmes are not only compliant with this generic framework, but also with “diverse flavours”. There are programmes focused on engineering (most providers), business, product design or media and with different operational approaches. By default, EPS, as an engineering capstone programme framework, is intended for the final year of the engineering programme. There are programmes offered to 3rd year students (all providers), to 3rd and 4th year students (Polytechnic Institute of Porto) and 3rd, 4th and 5th year students.

2.2 EPS@ISEP

The School of Engineering of the Porto Polytechnic (ISEP/PPorto) became an EPS provider in 2011 and has since welcomed 3rd and 4th year mobility students during the spring semester. EPS@ISEP – the EPS programme provided by ISEP/PPorto – targets engineering, business and product design students and aims to prepare them for their professional life by fostering the autonomous development of scientific, technical, personal and social skills

The EPS@ISEP programme is structured in six modules: 20 ECTU assigned for the project module and 10 ECTU for complementary modules: Project Management and Team Work (2 ECTU), Marketing and Communication (2 ECTU), Foreign Language (2 ECTU), Energy and Sustainable Development (2 ECTU) and Ethics and Deontology (2 ECTU). The latter are project supportive seminars, oriented towards the specificities of each project, focussed on the development of the soft skills essential in the training of twenty-first century engineers: communication (including technical-scientific English) contributes to the development of the project deliverables; project management focuses on task identification, human resource allocation, task planning and scheduling, resource management, plan enforcing and eventual rescheduling; sustainability addresses the ecological footprint; ethics and deontology analyses the ethical and deontological concerns; and marketing tackles the market analysis, segmentation and positioning of the prototype [9]. There is also an Arduino crash course to provide students with basic knowledge about this simple control platform. Figure 1 presents the EPS@ISEP schedule and illustrates the concretization of golden rules *viii* and *x*.

Before the beginning of the semester, a set of project proposals regarding real world problems are collected, each one with a specific client, with a strong focus on sustainability, to raise the student’s awareness to the problem, and in multidisciplinary topics, so each team member can contribute to the project with his/her previous knowledge and background experience. The origin of proposals ranges from industry, services, R&D institutions or the school itself. The proposals tend to be multidisciplinary problems, i.e., require the integration of multiple technical and scientific competences. A proposal defines the problem/challenge to tackle, the minimal set of requirements, mostly mandatory directives and standards, and the maximum budget. This type of proposal directs the team towards the design thinking stages and, then,

towards the development and operation stages of the capstone project/internship. As all proposed projects are open ended, team discussions about the possible solutions provide an opportunity for the students to expose their different beliefs and values, in a multicultural setting. Depending on the complexity of the projects, the average budget of an EPS@ISEP project is typically around 150 €~ 250 €.

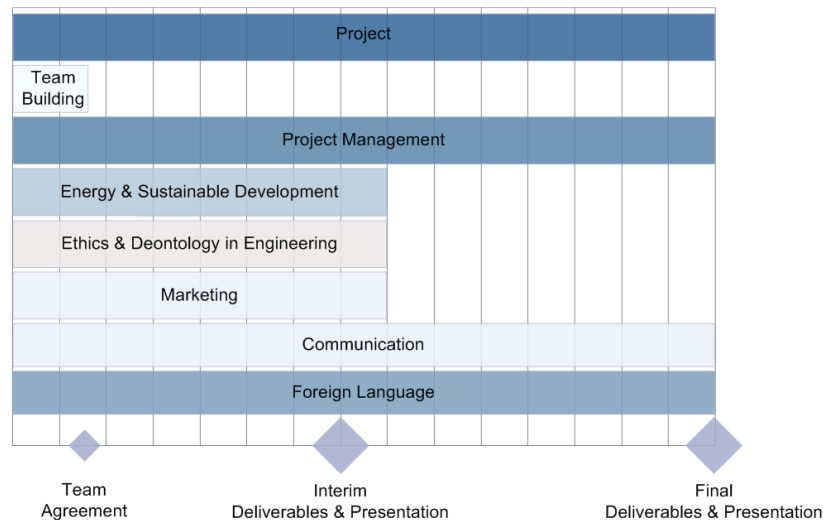


Fig. 1. EPS@ISEP schedule

Before the semester start, each student fills a Belbin questionnaire, used to identify its individual teamwork profile and design of teams according to rule *ii*. According to the EPS rules, not only teams must incorporate students from different fields of expertise and nationalities, but team building activities must be offered to allow team members to discover and perceive the existing cultural, scientific and personality differences. One of the first tasks team members face during team building activities (rule *viii*), is to define their own set of conflict resolution rules – Team Work Agreement – using the mechanism described by Hansen [10]. The resulting document, signed by all team members, is archived in the team folder. Next, teams select their project from the list of project proposals available and start their learning journey by conducting studies on marketing, ethics, deontology and sustainability together with scientific research (a state of the art analysis of the problem domain) to decide on the structure design and materials, as well as on the system design and control system. Students also must address other aspects concerning their projects, namely the detailed project planning and scheduling for the entire duration of the work.

EPS@ISEP adopts a unique supervision model where a panel of multidisciplinary experts, consisting of teachers from various study fields, acts as a consulting committee (Figure 2). Every week, this panel meets with each team for about 40 min during the weekly supervision meeting.

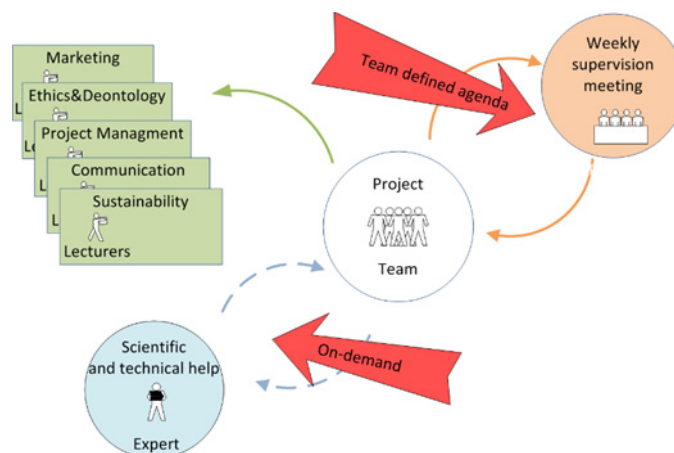


Fig. 2. EPS@ISEP model of student supervision

In the meeting with the panel, the teams conduct the meeting, and only the topics previously specified by the team in the wiki agenda are discussed. In this meeting, the teams are challenged to explain and justify any decisions taken during the previous week (shared in advance on the project wiki) and motivated to explore further. To be effective, the coaching panel is aware that it is interacting with students from diverse scientific and cultural backgrounds as well as that it must provide prompt feedback. In addition, the teams hold weekly meetings with their direct project supervisor(s) to promote further brainstorming, debugging, assembling and testing of the project. The teams can take the initiative to propose additional coaching meetings.

Assessment drives learning and hence a good assessment design is the key to effective student development [11]. EPS@ISEP uses the assessment scheme proposed by Hansen [10]. Assessment occurs twice during the semester and contemplates self and peer (S&P) and supervisor assessment (SA). The S&P assessment considers the quality and quantity of the technical contribution, openness to others ideas, teamwork performance, leadership, attitude and initiative shown [12]. The SA assessment reflects both team performance as well as the individual performance of each student. The interim assessment is intended to give individuals and teams feedback about their performance so far, from the point of view of their peers and of the supervisors. The supervisors use the assessment to monitor team working and to give constructive feedback and advice where needed [12].

The teams must produce several deliverables, including the project wiki, report, video, paper, manual, brochure and a proof of concept prototype. The report structure (provided beforehand) includes as mandatory sections the introduction, state of the art, marketing, sustainability, ethical concerns, project development and conclusions. Some chapters are produced and refined within the corresponding complementary modules. The structure and presentation of the deliverables are addressed in the communication seminar. The wiki is a key tool to the EPS process since it acts as a collaborative work platform and as the project show case.

3 Examples of EPS@ISEP Projects Aligned with the UNESCO Millennium Development Goals

In this section are introduced and described three examples of projects developed in the scope of EPS@ISEP, which are aligned with the UNESCO Millennium Development Goals 1 and 7.

3.1 Aquaponics System

In 2014 one of the EPS@ISEP project proposals was the development of an Aquaponics System, incorporating eco-friendly sustainable techniques. Aquaponics systems have received increased attention recently due to its possibilities in helping reduce strain on resources within 1st and 3rd world countries. Aquaponics is the combination of Hydroponics and Aquaculture and mimics a natural environment to successfully apply and enhance the understanding of natural cycles within an indoor process. By using this knowledge of natural cycles, it is possible to create a system with capabilities like that of a natural environment with the benefits of electronic adaptations to enhance the overall efficiency of the system.

The goal was to design and build an aquaponics system, as sustainable as possible, to support both fish and plant culture, based on water recirculation, limited to an overall budget for the prototype of 250 € [13]. The system should be able to monitor and control the most important system parameters, to ensure good conditions for both fish and plants, implying using sensors to check temperature and other parameters.

The multinational team involved in its development was composed of five students, with different nationalities and backgrounds: a Spanish Mechanical Engineer student, an English student of Electrical, Electronic and Energy Engineering, a French student of Environmental Sciences, a Polish studying Logistics and a student of Product Design from the UK. Their motivation for choosing this project was that: *“As a group we came to an early decision that we would like to choose a proposal that incorporated sustainable techniques and been eco-friendly, as this is the future of all Design/Engineering. As a group we were all interested in creating our own Aquaponics system as this is a system/technique that is becoming ever more popular throughout the world, more so in poorer regions and where water is a limited resource.”* [14].

The team started by making a study of the state of the art in this scientific field, focusing in Aquaculture and Hydroponics, and their integration, i.e., Aquaponics, which is based on a natural productive system. It can be described as the combination of Aquaculture and Hydroponics and this is where the name comes from: Aqua-ponics. Hydroponic systems rely on the use of nutrients made by humans (chemicals, mineral salts and trace elements) for optimum growth of plants. Water in hydroponic systems must be discharged periodically, so that the salts and chemicals do not accumulate in the water, which could become very toxic to plants. Aquaponics combines the two systems in a symbiotic environment, cancelling the negative aspects of each. Instead of adding toxic chemical solutions to cultivate plants, Aquaponics uses highly nutrient effluent from fish that contain virtually all the nutrients needed for optimum growth

of plants. Aquaponics uses plants to cleanse and purify the water, after which the water is put back in the aquarium. This water can be re-used but must be topped up at certain stages due to losses from evaporation and plant usage. A simple flood and drain system is what will be operated so the plants are able to receive oxygen and small breaks from the water to reduce the chance of root-rot [15].

In order to build a prototype with a high-quality standard, research into Aquaponics was performed, covering the existing methods and technologies. There are three commonly used types of aquaponics systems [16]: Media Filled Beds, Nutrient Film Technique and Deep-Water Culture. Since the media-based system was found to be the most reliable and simplest method of Aquaponics, and requires the least maintenance in comparison to the other types studied, the prototype was built this way [16].

The state-of-the-art survey analysed existing commercial aquaponics systems and several prototypes under development. Several aquaponics systems were found on the market [14] but the market shrinks vastly for Indoor Aquaponics systems. This market can be further reduced by adding the term ‘Designer’ to the aquaponics system, as many consumers do not want to decorate their home with unpleasant objects. From the research conducted, no commercial producers of aquaponics systems were found in Europe. Overall, there has been identified only one real competitor in the household aquaponics market [17]. All other systems reviewed lack the necessary appealing design to be placed indoors as an adornment [18-20].

There are some basic components that every aquaponics system needs, regardless of its type, namely: (i) a fish tank whose size depends on the number of fish to accommodate and on the size of the grow bed; (ii) a grow bed and growing medium, simply a suitable container that is filled with a growing media such as gravel, hydroton (expanded clay) or lava rock; (iii) a pump; (iv) tubing; (v) plants, since the Aquaponics System is described as a small kitchen garden, was suggested growing common herbs such as basil, thyme or rosemary; and (vi) fish – in this case, the tank was stocked with Convict cichlids (*Amatitlania nigrofasciata*) since they do not require much space and are easy to take care.

The design and development of an Aquaponics System emphasizes the eco-efficiency measures for sustainability considered during the system development. During the project, the team addressed the three spheres of sustainability, namely the environmental, economic and social impacts associated with the product they purposed to develop, as well as its lifecycle analysis [14]. Aquaponics reduces the strain on resources by allowing the user to both breed and eat the fish within the system and grow/harvest the produced plants. This system is not fully sustainable but has a significant reduction on resources such as water, requiring only 10 % compared to agricultural farming.

In parallel with this study, in the Marketing and Communication module, the students defined the market plan for the product. They researched the market and identified the customer’s requirements, to define a product fitting into these needs. This allowed the team to create a customer orientated marketing strategy and develop an integrated marketing program. With this purpose, the team performed an environmental analysis, consisting of a Political, Economic, Social and Technological analysis (PEST-Analysis) of the macro-environment and micro environment, and a Strengths,

Weaknesses, Opportunities and Threats (SWOT) analysis, defined the strategic objectives for the project, performed the market segmentation, defined the positioning of the product and, finally, defined the marketing mix. Based on the market analysis [14], the team decided to target the household market, as a small system would be easier to control and keep sustainable compared to a large (small farm) sized system. Such a system would also allow creating an aesthetic product for the home, easier control over the environment and require a smaller electronic system. Furthermore, as previously stated, even though there are several aquaponics systems in use at a large scale, there are not many for indoors usage, making this area an interesting target market, and with the recent increase in both sustainable products and the purchase of organic foods, there is a large market share available for quality aquaponics systems.

Finally, in the Ethics and Deontology module, the students analysed the ethical issues surrounding the product as well as more general ethics on a wider range of topics. Regarding the concerns faced while developing the aquaponics system, students addressed aspects related with engineering ethics, sales and marketing ethics, academic ethics, environmental ethics, liability aspects, and intellectual property rights.

Since the project proposal did not impose any restraints on the physical appearance of the product, the team could be creative during the design process, while also considering its manufacturing. The grow bed design followed the shape of the cuboid tank, apart from an area taken out the back-middle section allowing the pump to sit in the middle of the tank and feeding of the fish with ease. This area will often be covered from view by the plants growing within the grow bed and does not take anything away from the physical appearance of the tank itself (Figure 3, left).



Fig. 3. Design of the Aquaponics System (left) and picture of the final assembled system (right)

Given these ideas, the team developed the mechanical architecture for the Aquaponics System considering the required tank and grow bed, and the need to circulate the water among these two sub-systems considering a fail-safe design. There was the need to plan the placement of the electronics, which required a large amount of time, due to the safety risk of electronics contacting water [14]. It was decided to create a space within the grow bed for the electronics. This small area comes with a lid for

easy removal of the electronics while also keeping it safe from water splashes. The housing also includes a small cut out from the back where the wires can pass through so that the lid can stay secure [14].

Since aquaponics systems need to frequently check the water temperature and pH level, the Aquaponics System should ideally monitor temperature, pH and the ability of oxidation / reduction potential (ORP) of the tank, and display the results on a Liquid Crystal Display (LCD) screen, and control the water flow. A microcontroller board is responsible for performing these tasks automatically.

The next step was to choose the components and assemble the electronic control system. An Arduino Duemilanove ARDU-004 motherboard, programmable with the free Arduino software, was chosen. The selected LCD module, was connected to the power supply (5 V) and to the Arduino motherboard. The temperature sensor chosen was the DS18B20, since it is waterproof, has a temperature range sufficient for the application and is powered by the data line to the Phidget Interface Kit 8/8/8 Model: PHD-1018_2. The ASP2000 pH sensor was selected to measure the pH level from 0 to 14. Since all selected components need 5 V, the choice was the INM-0761 power supply, which outputs sufficient current for the whole control system (2.5 A) [14].

The Aquaponics System operates as following:

1. The water from the fish tank is pumped in the grow bed by the water pump. The pump is controlled by the Arduino, manipulated by the relay and programmed to switch on/off at certain intervals.
2. When the water level reaches the upper limit of the siphon bell, the grow bed is emptied and refilled. This process operates intermittently throughout the time duration that the pump is turned on. At this moment plants are provided with necessary nutrients and then water flows back to the fish tank through a small pipe.
3. Sensors within the tank send information to the Arduino, which is displayed on the LCD screen.

If, for an unknown reason, the siphon bell does not work, or is not sufficient to discharge the water at the same rate that the pump fills the grow bed, two side outputs ensure that the water level inside the grow bed does not increase and overflow out of the aquaponics system.

Tests were performed to ensure that all components were safe within the electronic system. Additionally, were completed tests to check three different areas of the electronics: (i) relay; (ii) current driver; and (iii) sensors. All these tests were accomplished successfully.

Figure 1 (right) depicts a photo of the assembled Aquaponics System. The system has been running successfully for about three years. It has sustained several Cichlid (*Amatitlania nigrofasciata*) fishes together with two ornamental plants: maidenhair fern (*Adiantum capillus veneri*) and creeping fig or climbing fig (*Ficus pumila*). During this period, the plants had to be pruned several times due to extensive growth.

As a concluding remark, the main objective was to create a working system that supported both fish and plant cultures and, through research and development, it is believed that a system has been created that can complete the required objective and be aesthetically pleasing. Due to the electronics put in place within the system, it is

possible to monitor the system and ensure optimum conditions permanently. To be sustainable, the system runs at 15 min to 30 min intervals. This saves power compared to a continuous system and provides plants extra oxygen in order for quicker growth. The students state that *“we have completed the requirements and also expanded so that the system will be successful within the intended target market due to an aesthetic design and simple functionality.”*

Regarding the process, the team reports that: *“After moving swiftly through the design stages and using all aspects (ethics, marketing, etc.) to create a quality design, we found that it was possible to create a simple product that fitted our needs. However, the technology/electronics that would be incorporated in the system also affected the final design due to restraints regarding size and placement. Taking this into account we developed an attractive system that combines art and technology together. Through development we were pushed to change many features of the design and many of these simplified the final product and led to an overall cheaper and easy to manufacture prototype. Overall, we found that from the initial brainstorming to the final renders, our ideas of a successful and quality aquaponics system had changed vastly. This knowledge was gained mostly through research and we believe that this led to the creation of a desirable and functioning system that fits well into the intended markets.”*

In the end of this project, the team members gained new knowledge and skills difficult to achieve in a traditional capstone project. The project itself is a fact of sustainable fish breeding and plant cultivation biology. Having the smart aquaponics system is an asset to the users, and this effort to add electronics and computing was a successful exercise of union of the chores of various aspects in which each specialty can only be enriched by the harmonization of all the different knowledge needed.

A more detailed description of this project can be found in this team final report [14] or on an accompanying paper [21].

3.2 Insectarium

One of the EPS@ISEP project proposals offered in 2015 was the development of an insectarium, encompassing two goals: (i) to raise student awareness to the problem of sustainable food production; and (ii) to design and develop a functional, cost-effective, eco-friendly and attractive insectarium prototype. As all EPS projects (each one with a specific client, responsible for defining the project requirements and checking its compliance), the objectives of the insectarium proposal were broad, and addressed: *“... the problem of how to produce food to feed the world's population. Since recent figures indicate that there are more than 200 million insects for each human on the planet, the challenge is to build an enclosure with the appropriate conditions to grow insects (e.g. mealworm or Tenebrio). This insectarium should be inexpensive, productive and have an elegant and functional design.”* [22].

The team that choose this project was composed of six students from different nationalities (Belgian, Polish, German, Spanish, Estonian and Scottish), and backgrounds (Digital media and graphic design, Computer science, Marketing, sales and purchases, Building engineering, Environmental engineering and Electronic engineer-

ing). The technical objective of the project was to create a functional, cost-effective, eco-friendly and attractive insectarium prototype.

The concept of insect farming is relatively new. Insects are reared in a confined area (*i.e.*, a farm) where the living conditions, diet and food quality are controlled. Farmed insects are kept in captivity, isolated from their natural populations [23]. One of its advantages is the relatively small ecological footprint compared to conventional livestock farming in terms of: (*i*) land use, (*ii*) the efficiency in converting feed into high value animal protein; and (*iii*) greenhouse gas and ammonia emission.

Studies conducted in the Netherlands, where mealworms are often cultivated as food for reptile and amphibian pets, concluded that insects, like mealworms, can help to solve this problem. Researchers, which analysed every input used in the process of breeding the worms, show that worms are a protein source considerably more eco-friendly than conventional protein sources. Insect farming requires less energy and produces less carbon dioxide into the atmosphere when compared with the production of milk, pork, chicken or beef. Pound for pound, mealworm protein (green) produces much lower amounts of greenhouse gas emissions than both the high (red) and low (blue) estimates for conventional protein sources [24].

After exploiting the topic, the team considered growing insects not only for animal feed, but also for human food. Their motivation resulted from the fact that insects are more sustainable, *i.e.*, require quite less resources per kg of protein, compared with traditional sources of protein. This approach, in the current Earth's population growth scenario, contributes to minimise the resources required for meeting food needs.

Driven by this multidisciplinary problem, the team performed: (*i*) a survey of competing products; (*ii*) a selection of the insect species to grow based on the study and comparison of the life cycle and habitat requirements of different species of insects; (*iii*) a marketing plan; (*iv*) a sustainability and an ethic and deontological analysis of the proposed solution; and (*v*) the design, assembling and testing of the prototype.

Although the insectarium may be used to house different insects because of the controllable temperature and humidity, the focus is on production of mealworms since they can be eaten by animals and humans. Moreover, compared to other insects, they contain a high level of protein and are one of the easiest insect species to grow.

Mealworms are the larval form of the mealworm beetle, *Tenebrio molitor*, a species of darkling beetle. Like all holometabolic insects, they go through four life stages: egg, larva, pupa and adult. Mealworms live in areas surrounded by what they eat under rocks, logs, in animal burrows and stored grains. They clean up after plants and animals and, therefore, can be found anywhere where there are such leftovers. Raising mealworms is fairly easy since they are prolific breeders and are hardy insects. Their growth is affected by the temperature and humidity. The ideal temperature and humidity for growing a colony is around 25 °C -27 °C and 70 % humidity, respectively.

Domestic *Tenebrio molitor* colonies usually hatch and live in standard plastic containers. The container should be kept away from windows and direct sunlight to prevent the temperature from rising. The daily light cycle is adequate, *i.e.* the process does not require artificial lighting. A colony of mealworms will reproduce faster with a higher humidity, but, in most cases, the natural humidity in the air will be sufficient. In a dry climate, it may be necessary to raise the humidity. The substrate of the con-

tainer will be the food – wheat bran, oatmeal, cornmeal, wheat flour, ground up dry dog food or a mixture of these dry foods. Slices of potatoes, apples, carrots, lettuce, cabbage or other fruits and vegetables are used to supply water to the worms. Potatoes are often preferred since they last a while and do not grow mould.

In Europe insect farming is at an early stage. The European Commission is currently co-financing a research project to explore the feasibility of using insect as a protein source, following a recommendation of the European Food Safety Authority [25]. The European Union prohibits the use of insects to feed livestock. Nevertheless, there are large companies investing in the sector like Proti-Farm, a producer of insect ingredients for the food and pharmaceutical industry [26]. In 2014, it acquired Kreca, a company with in-house knowledge of breeding and rearing 13 different species of insects [27]. Kreca's production, which includes 12 different insect species, is intended for human food (5 %) and pet food (95 %) [27]. The farm consists of eight barns where the temperature varies between 25 °C and 30 °C, depending on the insect species. The insects are fed on corn or groat meal obtained from local providers. Inside the barns, racks of boxes hold hundreds of kilograms of insects, eating several tonnes of meal and producing a few tonnes of insects per week. Proti-Farm sells whole insects, protein powders (isolated, concentrated, hydrolysed) and (refined) lipids.

During the elaboration of the marketing plan, the team conducted the SWOT analysis, performed market segmentation and defined the marketing programme for the product, concluding that the market offers many different types of bug-specific farming structures. However, it is lacking a general solution for household users, *i.e.* a solution for farming different species of insects. As a result, the team decided to create a home insectarium to house different species. For example, Space for Life suggests and provides instructions for raising ants, house crickets, mealworms, praying mantids and monarch butterflies at home [28]. Since the light, temperature and humidity requirements differ from species to species [28], such a product must be reconfigurable. Ideally, the insectarium should include a control system to operate the heating, cooling and lighting subsystems in accordance with the readings from the installed temperature, humidity and light sensors. In addition, since it is intended for the domestic market, it should be attractive and easy to maintain. Figure 4 shows the initial structure drawings and the brand logo INSECTO, which were defined together with the marketing plan [22].

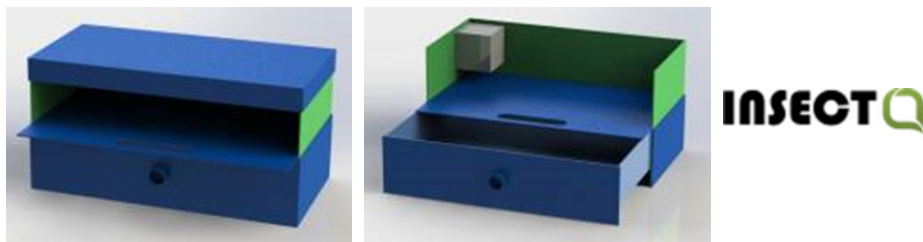


Fig. 4. First sketches of the Insectarium (left and centre) and INSECTO brand logo (right)

In terms of the structure, the team chose to keep the manufacturing, assembling and maintenance simple and easy. The result was INSECTO – a boxy, modular insectarium composed of a reduced number of parts – which allows stacking for larger production schemes. The team selected acrylic glass – polymethyl methacrylate (PMMA) – to build the structure of the insectarium since it is a durable material with a long-life cycle and a good temperature and sound isolation. The PMMA temperature insulation maintains the insects at a comfortable temperature with low power consumption. The electronic components were chosen according to their energy consumption (sustainability) and the selected software was open source (cost).

The air conditioning of the insectarium (temperature and humidity) is the main technical aspect of the project. Air conditioning can be divided into heating, cooling, humidification and dehumidification processes with specific energy demands. Since the simultaneous control of temperature and humidity is complex and exceeded the pre-defined budget (100 €), the team decided to incorporate in the insectarium two additional elements: an air heating resistor, to raise the internal temperature, and an air renewing fan, to reduce both the internal temperature and humidity.

The main function of the insectarium is to provide different species of insects with an appropriate environment to grow and reproduce. This was achieved by creating a configurable automatic humidity and temperature control system. The user can specify the desired temperature (°C) and humidity (%), the maximum temperature (°C) and humidity (%) variation, the percentage of heat power and the fan speed.

To control automatically the temperature and humidity inside the insectarium, was used a microcontroller board, a humidity sensor, a temperature sensor, a resistor, a fan and a LCD with a keyboard for the user interface. The microcontroller is connected to the humidity and temperature sensors (inputs), the keyboard (inputs), the LCD (output), the resistor (output) and to the fan (output). The microcontroller controls the fan speed and the resistor power through pulse width modulation (PWM).

The team performed the selection of materials and solutions, analysing the quality, economy and sustainability aspects. The structure was built reusing existing PMMA leftovers. For the control system, according to the study undertaken, the team chose: (i) an Arduino Uno microcontroller; (ii) a DHT22 humidity and temperature sensor with an accuracy of $\pm 2\%$ for the humidity and $\pm 0.5\text{ }^{\circ}\text{C}$ for the temperature; (iii) a $28\ \Omega$ resistor (reused from a toaster); (iv) a 12 V 0.13 A fan (reused from a Personal Computer); (v) a ULN2003A high-current Darlington transistor array to boost the current for the fan and resistor; (vi) an Itead 1602 LCD shield with keyboard; and (vii) a power supply AC/DC 230 V AC/12 V 2 A [22]. The cost of these components was 60 €.

The proposed system differs from the Do It Yourself (DIY) home solutions because it is modular, reconfigurable (via the user interface) and automatically controls (via the control system) the most relevant environmental parameters (temperature and humidity) for breeding different species of insects at home. This approach meets the client requirements and extends further the spectrum of possible clients.

The power consumption estimation (in the most demanding scenario) of any electric appliance is a sustainability indicator. In a continuous operation scenario, the Arduino, LCD shield and the sensors are always on. In this situation, the estimated

annual power consumption is 7.6 kWh. In addition, in the worst-case scenario, the heater or the fan will be on, but not simultaneously. When the heater is also on, the estimated annual power consumption reaches 49.6 kWh. This results in an estimated annual average power consumption of 26.5 kWh (equivalent to a 3 W lamp).

Initially, the team undertook basic tests regarding: (i) the heating and cooling functions (to determine the maximum attained temperature and the fan ability to renew the air) without control; and (ii) the debugging and validation of the control code. With the resistor connected to 12 V, it took in average 227 min to raise the internal temperature from 24 °C to 31 °C and, once it reached this maximum value, it stabilized. With the fan connected to 12 V, the temperature inside diminishes until it reaches the external room temperature. For example, lowering the internal temperature from 31 °C to 27 °C (room temperature) took 50 min.

Finally, with the insectarium prototype assembled (depicted in Figure 5), the team conducted the functional tests and measured the actual power consumption. These tests contemplated the normal operation of the insectarium, i.e. the maintenance of the temperature and humidity parameters within the user specified values. The user interface menu was fully functional, allowing the user to specify the desired input parameters. The control system was able to maintain the internal temperature and humidity within the user specified values and the power consumption measured in the three operation modes (idle, air heating and air renewal), resulted in an average annual power consumption of 24.1 kWh (lower than the estimated 26.5 kWh).



Fig. 5. Photographs of the assembled insectarium

The team perceived the project development process as “[...] a fun and exhilarating challenge from which we benefited greatly as an experience for our careers by living in a different country and working with people from all over Europe.”, and the INSECTO prototype as “[...] a product that provides sustainable food for now, but, more important, for the future”, while aiming “[...] to be as sustainable as possible [...] and innovative compared to other insectarium products.” [22]. These views illustrate the relevance the team attributed to this project in terms of multicultural teamwork and sustainable development practices.

A more detailed description of this project can be found in this team final report [22] or on an accompanying paper [29].

3.3 Escargot Nursery

In 2017 an EPS@ISEP team composed of a Biology and Medical Laboratory student from the Netherlands, a Product Development student from Belgium, a Mechani-

cal Electronic Systems Engineering student from Scotland, a General Engineering student from France, and an Engineering and Architecture student from Spain, chose to develop an Escargot Nursery [30]. The challenge was to design, develop and test a snail farm compliant with the applicable EU directives.

Nowadays, while many tend to live disentangled from the natural habitat, others are in pursuit of natural processes and experiences. On one hand, the digital revolution, which improved communication channels through social media, mobile phones and video conferencing, also isolated people from a real social life. On the other hand, more people are aware of the use of genetically modified organisms and, consequently, want to know the origins and growth processes of their food. Genetic modification is being used to improve the colour, smell and taste of food, trying to make it more attractive and durable in terms of the shelf life. However, there is not enough scientific knowledge regarding its long-term side effects on people [31].

The team saw this project as an opportunity to contribute to the mitigation of both problems by deciding to build a unique and innovative product to help people produce their own snails at home for educational and consumption purposes. The focus was on the design of an educational product mainly targeted for families with children. This would help children relate and establish bonds with nature, while developing autonomy, responsibility and an interest in science. To create a new and fun way of producing food, the team identified the need to include technology and create a comfortable habitat for the snails, allowing the end user to grow snails for food or as pets.

The team performed a series of background studies to specify the requirements, design and control system of “EscarGO”. There are several snail farms available on the market. Since most of the home-use competitors of the “EscarGO” were not designed for snails, a comparison between large scale snail farming solutions was made. The team considered this comparison relevant to the development of the product, due to the lack of technologies used in the products for domestic use. These technologies were dedicated to the production of a much larger number of snails, whereas this project is designed for a much smaller number and for domestic use.

After this comparison, the team decided to choose the species that seemed the most relevant, with the goal to adapt the product to this particular species. It was decided to use the *Cornu aspersum*, one of the most common snail breeds and the most consumed in France, the main market target. The *Cornu aspersum* species belongs to the Gastropoda class and they prefer an undisturbed habitat with adequate high moisture level and good food supply, and it takes six months to grow to their optimal size [32]

This species needs a specific habitat. First, these snails require a temperature between 15 °C and 25 °C, with an optimal temperature of 21 °C [30]. The humidity level is essential for the activity of the snails. They are more comfortable with humidity levels from 75 % to 90 %. For an optimal reproduction and breeding process, the snails require 16 h/d of light [30]. Finally, the snail population density must be considered since too many snails have a negative impact in their successful growth and breeding. The recommended density for *Cornu aspersum* is 1.0 to 1.5 kg/m². Since an adult snail weights approximately 10 g, it was possible to have up to 100 snails/m² [30].

Based on this study, the team derived the following requirements: (i) breed up to 50 snails, producing two meals a year for a family of four; (ii) design a terrarium with dimension of $400 \times 300 \times 375$ mm; and (iii) include a light, humidity and temperature control system to make the product user-friendly. It should be kept on mind that when the user touches the snails, for hygiene purposes, it is necessary to wash their hands.

During the marketing study, the team worked on logos and commercial names and decided to launch “EscarGO” in France, since the cultural barriers related to snails consumption seem more diluted. The product is to be sold on the Internet, targeting the gourmet costumer, wanting to grow snails at home for self-consumption, and the parent costumer, wanting an educational and recreational product. Despite no competitors were identified during the study, the team determined the need to keep the production costs low enough to generate profit while selling the product at a competitive price of 50 € to 70 €. In terms of marketing plan, the team concluded that “EscarGO” should be a domestic product and, therefore, its dimensions should not be bigger than any other home-size product, *e.g.*, a microwave, while being able to host 50 snails.

Concerning the product sustainability, its design must be simple to reduce the environmental impact. The team tried to create a low impact system by choosing low impact materials and recycling as much as possible. The structure of the final product is in polypropylene (PP) since it is resistant to the growth of bacteria and has a lower impact on the environment compared with other plastics. Due to budget constraints, the team chose to use Polyvinyl Chloride (PVC) for the prototype structure. Finally, it was decided to use the curtain method to increase the liveable surface area for the snails, while keeping the dimensions smaller. This method consists of two curtains, made of Nylon mesh, allowing hosting more snails in a smaller space.

The team adopted the French ethics charter for engineers drafted by CNISF, since the target is the French market, and made every effort to create a safe and sustainable Escargot Nursery, *i.e.*, with a minimal impact on the environment regarding to the environmental ethics [33].

The team started by specifying the project requirements. The requirements imposed in the project proposal were using sustainable materials, using low cost hardware solutions and sticking to the budget 100 €. Additionally, the Escargot Nursery had to meet other requirements, namely an aesthetically pleasing design, as the product would be on display, so the team wanted the product to be an attractive appliance. Regarding its electronics, the team wanted the escargot nursery to be as fully automated as possible, with little need for human interaction. It had to be able to set and display the temperature, humidity and light, while using as little power as possible.

Ease of use was one of the most important design motivators of “EscarGO”. The Escargot Nursery is expected to achieve certain functions. It has to keep the climate inside at a comfortable level for the snails. For this, the humidity needs to be controlled, so a liquid spray system needs to be used to keep the soil moist, the temperature also needs to be kept within the safe range, *i.e.* between 15 °C and 25 °C. Lighting in the form of LED needs to be controlled to ensure the snails have enough light to thrive. The system measures the temperature and humidity inside the nursery and measures the light level outside the nursery. The program stored in the Arduino board gathers information and controls each output, to ensure automatic climate control.

The final design of the “EscarGO” is minimalistic yet functional (see Figure 6). The housing is made of black and white PP, and the front and rear cover have a transparent area made of PMMA. The black PP in the front covers a display with relevant information about temperature, humidity and light. On the top there are two removable plates: one gives access to the living environment of the snails and one to the water supply. The water supply and the curtains are easily removable for feeding and maintenance. The right side has openings to check the water level and vents for the fan and both sides are provided with sunken handles to easily move the product.

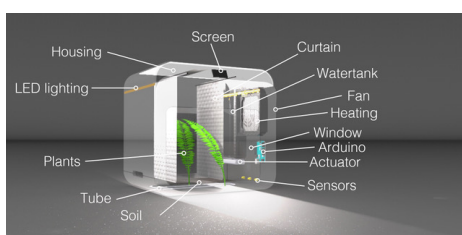


Fig. 6. 3D model of the “EscarGO” with all the components

Inside the nursery there are two compartments. A large one, equipped with planting, curtains, soil and small rocks to act as natural heat regulators, hosts the snail habitat. The curtains are made from Nylon mesh, so they are easy to clean. The tube under the soil helps to keep the humidity at a certain level. The LED lighting gives additional light when needed. All electronics are kept to the right side of the product in a smaller compartment, next to the water tank. These components are a microcontroller board, a fan, a heating device, an actuator and sensors. The microcontroller controls all processes so the snails can live in good conditions. The fan blows air into the nursery which can also be heated by the heating device. The actuator releases water from the tank to the tubing when the microcontroller sends a signal. The sensors give all the information needed to the microcontroller board. The 3D model of the product is depicted in Figure 6 with all its components.

Concerning the main functions of the “EscarGO” control system, an Arduino Uno is used as the microcontroller board. It was mainly chosen since the team did not have experience designing electronic systems, and had little coding experience, so the variety and number of Arduino Uno online tutorials made it the most attractive prospect.

The control system requirements are as follows. The enclosure needs to be able to maintain a comfortable temperature for the snails, without requiring much energy. It is recommended that the enclosure stays inside the home. Proposed is a heater element that will turn on if the temperature drops below 15 °C and a cooling fan that will turn on if the temperature rises above 25 °C. The final product uses power resistors as heating elements, and a fan to cool the air and provide air movement.

Humidity is another aspect that needs to be controlled. A moisture sensor was inserted into the enclosure, and there is a sprinkler hose pipe inside to release water if the environment is not humid enough. These have to be short bursts since over watering, or flooding, might drown the snails. There is also a possibility of a small water tank on the system for the humidity control so that the tank does not need to be fed

with a constant water supply. The team decided to use the DHT22 combined temperature and humidity sensor, to reduce the number of components and keep the electronics as compact, and with as little intrusion into the space as possible.

A final system requirement was to display the temperature and humidity on a small LCD screen.

One of the concerns with the project was that because there needed to be a humid environment for the snails, and they also required oxygen, there was the issue of dampness and humidity getting into the room where the terrarium is stored. This needs to be carefully controlled and monitored because dampness can cause damage to the room around the enclosure.

To evaluate the work and to make the product as safe as possible, the team performed functional tests, related with the verification of the correct operation of the control system, and soil tests [30]. The functional tests gave an insight into whether the Escargot Nursery complied with the requirements, and was ready to be produced and released onto the market. The soil tests focussed on the determination of the most appropriate soil conditions for growing snails.

Moisture along with available calcium content are two extremely important environmental factors that dictate the health of molluscan fauna such as snails. In order to keep the soil moist, two different strategies were used in the present work, namely the addition to the soil of calcium alginate microspheres or sodium polyacrylate particles. Alginate is a natural biodegradable polymer extracted from brown algae that forms hydrogels under mild conditions, in the presence of divalent cations, such as calcium. Sodium polyacrylate is a superabsorbent polymer that has the ability to absorb as much as 200 to 300 times its mass in water. It is frequently used in agriculture since it can absorb water when it rains and release it when needed [34].

The calcium alginate microsphere solution is the material of choice to keep the soil moist, not only because the humidity level was the highest attained during the whole test, but also because as they degrade, they release calcium into the soil, and calcium is very important for the snails' health. Snail shell is made of calcium carbonate and keeps growing as long as the snail grows. In this particular application, microspheres can act simultaneously as a water and calcium reservoir. Additionally, alginate microspheres can also be used as a controlled-release product of other substances that are identified as necessary for snail's development, such as, for instance, vitamins.

The team tested all electronic components separately, to be sure that all components worked, and then combined them to test the whole system.

Figure 7 displays the final prototype, which includes all the electronics for the optimal living conditions of the snails.

There were some problems with the development of the control system during the project due to some bad connections and since no team element had previously worked with Arduino. Nevertheless, the team solved everything and could do almost all tests. There were also some time constraints and, for this reason, it was not possible to test the water tank and the heating element could not be added on time for the prototype.



Fig. 7. Photographs of the assembled insectarium

However, and despite these minor problems, the different team members mention the following personal and learning outcomes of this process: “[...] I learned a lot of knowledge from my team members and it was really good for my development in the English language. [...] Going abroad on my own was far out my comfort zone. [...] I learned so much hard and soft skills while having the time of my life [...] [...] EPS was a brilliant opportunity for me to work with people from all over Europe on a project similar to what I would be expected to work on in a professional environment [...] [...] I have learned many things I did not know before about many different fields of knowledge and I have worked in a professional atmosphere similar to what I may have to deal with in the future [...]” [30].

A more detailed description of this project can be found in this team final report [30] or on an accompanying paper [35]

4 Discussion

In Project Based Learning courses, one of the main issues is getting an open project, as the basis of the student’s work. Often the teachers use the name Project incorrectly, when referring to a long practical work. In a real Project the solution to be implemented must be designed by the students, while on a practical work the technologies/solutions to be used are fixed by the teachers. As engineers, the teachers are more focused on the technological part of the solutions, so usually many Projects slowly morph into practical works.

One of obstacles to a more sustainability oriented curriculum is the pressure to teach “more engineering”. The usual faculty opposition is grounded on the argument that to teach sustainability, one must teach “less engineering”. From these projects one can see that while the focus was on sustainability, all the students were busy with engineering tasks.

The sustainable purpose of the project was incorporated in the requirements analysis, and to do the requirements analysis, cultural and social implications were considered. But, a correct design of an engineering system should always consider cultural and social implications. So as can be seen from these projects, the adoption of sustainable objectives in the EPS projects, has not resulted in “less engineering” education, but, on the contrary, has resulted in a better engineering education.

The sustainability focus of the projects helps to maintain the openness, and avoids purely technological project discussions, as can be seen in the students reports. So, the

focus on sustainability of EPS projects, exists not only for ethical reasons but also for strong pedagogical reasons.

In a sustainability oriented project, it may seem a mistake to include control electronics, microcontrollers and other sophisticated parts. This results of an effort to provide people with products/tools that allow them to be more involved in sustainable activities.

One of the main reasons why people are not more involved in sustainability related activities is lack of time, not absence of concern about sustainability or ecological issues. The sustainable care of plants or/and animals requires both the execution of tasks on a fixed schedule (feeding, watering, etc...) and the on-demand execution of other tasks on an unpredictable schedule (reacting to weather changes, abnormal conditions. etc...). The junction of these two types of schedules with a typical working life schedule may be impossible. The automation and/or the monitoring of some of the tasks related to sustainable activities may work as a catalyst to provide people already concerned by sustainability, the necessary conditions for a more practical involvement, and for them to pass from thoughts to action.

The sustainable focus of the EPS projects extends on the open source nature of all the produced documents, placed on the EPS Wiki, for general public availability and ease of maintenance, repair, customization and improvements.

So, the sustainability focus of the EPS projects not only has helped the students (and teachers) to think more about sustainability, but has provided them with a correct engineering mindset.

5 Conclusions

The EPS student-centred collaborative learning process is based on promoting the autonomy and responsibility in the teams, adopting technical and scientific coaching and offering project supportive and soft skills complementary modules. This process drives the teams to design and develop a concrete prototype and produce multiple deliverables, while learning to manage the project, to study the state of the art in the different fields of the project, to create a marketing plan, to work together and to justify all design, materials and development decisions based on the analysis of the sustainability, ethics, scientific and technological aspects.

In the EPS@ISEP Programme project proposals refer to open multidisciplinary real problems. Its purpose is to expose students to problems of a greater dimension and complexity than those faced throughout the degree programme as well as to put them in contact with the so-called real world, in opposition to the academic world.

A line that has been followed is to offer project proposals aligned with the United Nations Millennium Development Goals. Specifically, the design and development of sustainable systems for growing food (of which three examples have been described in this paper) allow students not only to reach the described objectives, but to foster sustainable development practices. As a result, we recommend the adoption of this category of projects within EPS for the benefit of engineering students and of the society.

6 Acknowledgment

This work was partially financed by the ERDF – European Regional Development Fund through the Operational Programme for Competitiveness and Internationalisation – COMPETE 2020 Programme within project POCI-01-0145-FEDER-006961, and by National Funds through the FCT – Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) as part of project UID/EEA/50014/2013, and also received financial support from the European Union (FEDER funds through COMPETE) and National Funds (FCT) through project UID/QUI/50006/2013.

7 References

- [1] Dillenbourg, P. (1999). What do you mean by collaborative learning?. In P. Dillenbourg (Ed.): Collaborative learning: Cognitive and Computational Approaches, Oxford: Elsevier, 1-19
- [2] Malheiro, B., Silva, M., Ribeiro, M. C., Guedes, P., Ferreira P. (2015). The European Project Semester at ISEP: The challenge of Educating Global Engineers. *European Journal of Engineering Education (EJEE) – Special Issue “Engineering Education: Challenges for Innovation”*. 40: 328-346.
- [3] Lehmann, M., P. Christensen, X. Du, and M Thrane (2008). Problem-oriented and project based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education. *European Journal of Engineering Education*. 33: 283-295. <https://doi.org/10.1080/03043790802088566>
- [4] What is Sustainability? (2016). Available online: <https://www.epa.gov/sustainability/learn-about-sustainability-what> [Last accessed: 02 January 2018]
- [5] MDG monitor (2017). Available online: <http://www.mdgmonitor.org/millennium-development-goals/> [Last accessed: 02 January 2018]
- [6] FAO (2014). Insects to feed the world. Available online: [http://foris.fao.org/meetings/download/2014/insects to feed the world/misc documents/summary report and abstract_book.pdf](http://foris.fao.org/meetings/download/2014/insects%20to%20feed%20the%20world/misc%20documents/summary%20report%20and%20abstract%20book.pdf) [Last accessed: 02 January 2018]
- [7] Andersen, A. (2012). The European Project Semester: A useful teaching method in engineering education. *Project Approaches to Learning in Engineering Education*, Sense Publishers, Rotterdam. 15-28. https://doi.org/10.1007/978-94-6091-958-9_3
- [8] Andersen, A. (2001). Implementation of engineering product design using international student teamwork to comply with future needs. *European Journal of Engineering Education*. 26: 179-186. <https://doi.org/10.1080/03043790110034438>
- [9] Malheiro, B., Silva, M., Ribeiro, M., Guedes, P., Ferreira, P. (2015). The European Project Semester at ISEP: The Challenge of Educating Global Engineers. *European Journal of Engineering Education*. 40: 328-346. <https://doi.org/10.1080/03043797.2014.960509>
- [10] Hansen, J. (2010). European Project Semester – how engineering students can achieve important competences. 5th International Conference on Engineering Education (ICEE 2010), Gliwice, Poland. pp. 1296-1298.
- [11] Rossiter, J. A. (2013). Case Studies in Making Assessment Efficient While Developing Student Professionalism and Managing Transition. *European Journal of Engineering Education*. 38: 582–594. <https://doi.org/10.1080/03043797.2013.824409>

- [12] Ashworth, D. W. C. (2011). Project-based learning in international teams – monitoring the effectiveness of teamwork. *Key Engineering Materials*. 450: 581-584. <https://doi.org/10.4028/www.scientific.net/KEM.450.581>
- [13] European Project Semester (2014). “Project description” [Online]. Available: http://ave.dee.isep.ipp.pt/~mbm/PROJE-EPS/1314/Proposals/EPS_PROJECT_2014_T5.pdf [Last accessed: 04 January 2018]
- [14] Sokolowska, N., Docherty, A., Llauradó, A. M., Keane, S., Méry, G. (2014). “Aquaponic Systems – Final Report” [Online]. Available: http://www.eps2014-wiki5.dee.isep.ipp.pt/lib/exe/fetch.php?media=aquaponicssystem_final.pdf [Last accessed: 02 January 2018]
- [15] Backyard Aquaponics (2012). “What is Aquaponics?” [Online]. Available: <http://www.backyardaquaponics.com/guide-to-aquaponics/what-is-aquaponics/> [Last accessed: 04 January 2018]
- [16] Backyard Aquaponics (2012). “Type of systems” [Online]. Available: <http://www.backyardaquaponics.com/guide-to-aquaponics/running-of-the-system/> [Last accessed: 04 January 2018]
- [17] Back to the Roots (n.d.). “Water Garden” [Online]. Available: <https://backtotheroots.com/collections/indoor-gardening-kits/products/watergarden> [Last accessed: 04 January 2018]
- [18] Back to the Roots (n.d.). “Back to the Roots” [Online]. Available: <https://www.backtotheroots.com/> [Last accessed: 04 January 2018]
- [19] Backyard Aquaponics (2012). “Backyard Aquaponics” [Online]. Available: <https://www.backyardaquaponics.com> [Last accessed: 04 January 2018]
- [20] Nelson Pade’s Inc. (2012). “Nelson Pade’s shop” [Online]. Available: <https://aquaponics.com/> [Last accessed: 04 January 2018]
- [21] Mesas Llauradó, A., Docherty, A., Méry, G., Sokolowska, N., Keane, S., Duarte, A., Malheiro, B., Ribeiro, C., Ferreira, F., Silva, M., Ferreira P., Guedes, P. (2015). Aquaponics System - An EPS@ISEP 2014 Spring Project. 3rd Technological Ecosystems for Enhancing Multiculturality (TEEM’2015), October 7-9 2015, Porto, Portugal. pp. 537-544 <https://doi.org/10.1145/2808580.2808662>
- [22] Bentin, C., Fountain, A., Davies, E., Bartosz, K., Toro Ronda, P., Suits, K. (2015). “Insectarium 2015 – Final Report” [Online]. Available: <http://www.eps2015-wiki3.dee.isep.ipp.pt/lib/exe/fetch.php?media=reportpdf.pdf> [Last accessed: 02 January]
- [23] FAO (2013). “Edible insects – Future prospects for food and feed security” [Online]. Available: <http://www.fao.org/docrep/018/i3253e/i3253e.pdf> [Last accessed: 04 January 2018]
- [24] Stromberg, J. (2012). “The Sustainable Meat of the Future: Mealworms?” [Online]. Available: <http://www.smithsonianmag.com/science-nature/the-sustainable-meat-of-the-future-mealworms-168571999/> [Last accessed: 04 January 2018]
- [25] Finke, M. D., Rojo, S., Roos, N., van Huis, A., Yen, A. (2015). The European Food Safety Authority scientific opinion on a risk profile related to production and consumption of insects as food and feed. *Journal of Insects as Food and Feed*. 1: 245-247. <https://doi.org/10.3920/JIFF2015.x006>
- [26] Tiny Farms (2012). “Tiny Farms – Pioneering the industrial production of edible insects” [Online]. Available: <http://www.tiny-farms.com/> [Last accessed: 04 January 2018]
- [27] Kreca (2018). “Kreca Living and freeze-dried insects” [Online]. Available: <http://www.krecafeed.com/> [Last accessed: 04 January 2018]
- [28] Space for Life (2018). “Raising insects” [Online]. Available: <http://espacepourlavie.ca/en/raising-insects> [Last accessed: 04 January 2018]

- [29] Fountain, A., Kuron, B., Bentin, C., Davies, E., Suits, K., Toro, P., Duarte, A., Malheiro, B., Ribeiro, M., Ferreira, F., Lima, L., Ferreira, P., Guedes, P. (2016). Learning Sustainability with EPS@ISEP – Development of an Insectarium. 8th International Symposium on Project Approaches in Engineering Education (PAEE'2016), July 6-8 2016, Guimarães, Portugal. pp 109-116
- [30] Borghuis, L., Calon, B., MacLean, J., Portefaix, J., Quero, R. (2017). “Escargot Nursery – Final Report” [Online]. Available: http://www.eps2017-wiki1.dee.isep.ipp.pt/lib/exe/fetch.php?media=final_report_3.pdf [Last accessed: 02 January]
- [31] World Health Organization (2014). “Frequently asked questions on genetically modified foods” [Online]. Available: http://www.who.int/foodsafety/areas_work/food-technology/faq-genetically-modified-food/en/ [Last accessed: 04 January 2018]
- [32] Croque Bourgogne (2016). “Quelles sont les différentes espèces d’escargots comestibles?” [Online]. Available: <http://www.croquebourgogne.com/index.php?rubrique=faq> [Last accessed: 04 January 2018]
- [33] Conseil National des Ingénieurs et des Scientifiques de France (2018). “Charter d’Ethique de l’Ingénieur.” [Online]. Available: http://guide.ensait.fr/lib/exe/fetch.php?media=charte_ethique-cnisf.pdf [Last accessed: 04 January 2018]
- [34] Puoci, F., Iemma, F., Spizzirri, U. G., Cirillo, G., Curcio, M., Picci, N. (2008). Polymer in Agriculture: a Review. American Journal of Agricultural and Biological Sciences. 3: 299-314. <https://doi.org/10.3844/ajabssp.2008.299.314>
- [35] Borghuis, L., Calon, B., MacLean, J., Portefaix, J., Quero, R., Duarte, A., Malheiro, B., Ribeiro, C., Ferreira, F., Silva, M. F., Ferreira, P., Guedes, P. (2017). Escargot Nursery – An EPS@ISEP 2017 Project. 20th International Conference on Collaborative Learning (ICL'2017); September 26-29 2017, Budapest, Hungary. pp. 1271-1282

8 Authors

Manuel F. Silva graduated, received the M.Sc. and the Ph.D. degrees in electrical and computer engineering from the Faculty of Engineering of the University of Porto, Portugal, in 1993, 1997 and 2005, respectively. He is Adjunct Professor at the Department of Electrical Engineering of the School of Engineering of the Porto Polytechnic (ISEP) and a Senior Researcher at INESC TEC. His research focuses on modelling, simulation, robotics and education in engineering and robotics.

Benedita Malheiro holds a five-year degree in electrical engineering followed by a M.Sc. and a Ph.D. in electrical and computers engineering from the Faculty of Engineering of the University of Porto. She is Adjunct Professor at the Electrical Engineering Department of ISEP and a researcher at INESC TEC, Porto, Portugal. Her research interests are in distributed, dynamic, decentralised intelligent problem-solving and engineering education.

Pedro Guedes holds a five-year degree in electrical and computers engineering from the Faculty of Engineering of the University of Porto, Portugal and a M.Sc. in Systems Control from the University of Technology of Compiègne, France. He is Adjunct Professor at the Mathematics Department of ISEP.

Abel J. Duarte has a BSc and a 5-year degree in chemical engineering from the Porto Polytechnic followed by a M.Sc. and a PhD in chemistry from the University of Porto. He is Adjunct Professor at the Department of Chemical Engineering of ISEP

and a researcher of REQUIMTE/LAQV. His research interests include sustainable development, biochemical systems and engineering education.

Paulo Ferreira graduated and received the MSc. degree in electrical and computer engineering from the Faculty of Engineering of the University of Porto, Portugal, in 1988 and 1994, respectively. He is Adjunct Professor at the Department of Informatics Engineering of ISEP. His research focuses on embedded systems. He is a member of the IEEE.

This article is a revised version of a paper presented at the International Conference on Interactive Collaborative Learning (ICL2017), held September 2017, in Budapest, Hungary. Article submitted 18 January 2018. Resubmitted 26 January 2018 . Final acceptance 30 January 2018. Final version published as submitted by the authors.