EDUCATION FOR SUSTAINABLE DEVELOPMENT: ENGINEERING STUDENT SUCCESS WITH EPS@ISEP

Benedita Malheiro[1,2], Pedro Guedes[1,2], Abel J. Duarte[1,3], Manuel F. Silva[1,2], Paulo Ferreira[1]

[1]School of Engineering, Polytechnic of Porto, Porto, Portugal, {mbm,pbg,ajd,mss,pdf}@isep.ipp.pt
[2]INESC TEC, Porto, Portugal
[3]REQUIMTE, School of Engineering, Polytechnic Institute of Porto, Porto, Portugal

Abstract. *Motivation is the key to academic success. In the case of engineering, autonomous project teamwork guided by ethics and sustainability concerns acts as a major student motivator. Moreover, it empowers students to become lifelong learners and agents of sustainable development. Engineering schools can thus address simultaneously these two essential education goals – learning and academic success – by challenging students to find innovative, sustainable solutions in a learner-centred set-up. This paper describes how the European Project Semester (EPS), a capstone engineering programme offered by the Instituto Superior de Engenharia do Porto (ISEP), combines challenge-based learning, ethics and sustainability-driven problem-solving, and international multidisciplinary teamwork to achieve both goals.*

Key words: Academic Success, Challenge-Based Learning, Engineering Education for Sustainable Development, European Project Semester, Multicultural and Multidisciplinary Teamwork, Project-Based Learning, Problem Solving.

INTRODUCTION

Educational literature has long identified strong correlations between student motivation and academic success (Haughery *et al.*, 2019). Academic success, which implies successful learning, involves academic achievement, satisfaction, attainment of learning outcomes, persistence, career success, acquisition of skills and competencies (York *et al.*, 2015).

To promote academic success among engineering undergraduates, programmes need to attract, motivate, and revolve around the learner. In this context, capstone design projects emerge as a promising learning framework. Specifically, assessment surveys have shown that: (*i*) students rank capstone activities highly (Lopatto, 2009); and (*ii*) undergraduate research programmes bring clear benefits for participating students (Fechheimer *et al.*, 2011). Moreover, to further motivate students, project briefs must address individual, social or planetary problems students relate with, be open-ended to promote innovation, and constitute meaningful challenges for students, namely, related to sustainable development. This idea of using active learning strategies, namely, challenge-based learning, to support integrative approaches to sustainability in higher education is advanced by several researchers, *e.g.*, Leal Filho *et al.* (2016) and Martínez Casanovas *et al.*, (2021).

This is the case of the European Project Semester (EPS), a semester-long student-centred engineering capstone programme (Duarte *et al.*, 2020). EPS integrates challenge-based learning with multicultural and multidisciplinary teamwork as well as challenges students to solve real problems following ethics and sustainability driven practices (Nylund & Malheiro, 2022). As such, it aims to motivate engineering students to become active proficient learners and future agents of sustainable change, promoting academic, personal, and social success. To prove such claim, the current contribution analyses the programme in terms of the academic achievement of the 228 alumni.

This document is organized in five additional sections. Section two presents the background; Section three engineering education for sustainable development and learner motivation; Section four the EPS concept and its implementation at ISEP; Section five analyses the academic success within EPS@ISEP; and Section six draws the conclusion.

BACKGROUND

The continuous demographic growth, associated with the rising expectations of populations, have placed unparalleled challenges to the planet. Pollution and depletion of resources such as water, soil or air, place enormous pressure on all habitats, leading to the extinction of species and the proliferation of others, irreversibly unbalancing the entire planet.

In 1972, the United Nations held the first world conference to address the impact of human activities in the environment. But it was not until two decades later, in Rio de Janeiro, that more than half of the world countries were able to commit to the preservation of the environment in the "Rio Declaration on Environment and Development", often shortened to "Rio Declaration" (United Nations, 1992). The fate of humanity could no longer be separated from that of the environment. Applications of the Rio Declaration were generic and quite ambitious, being difficult to implement. More recently, the United Nations launched a series of 17 sustainable development goals, with implementation starting in 2016, achievable in 15 years, with the principle of "leaving no one behind" (United Nations, 2022). These 17 goals relate to poverty, inequality, climate, environmental degradation, prosperity, peace, and justice. The achievement of these goals contributes to a more sustainable world.

The UNESCO report on engineering for sustainable development highlights the crucial role of engineering in achieving the sustainable development goals (UNESCO, 2021). Engineers are vital in addressing basic human needs such as alleviating poverty, supplying clean water and energy, responding to natural hazards, constructing resilient infrastructure, and bridging the development divide, among many other actions, leaving no one behind (UNESCO, 2021). Nonetheless, the question is how can engineers coordinate and apply appropriate practices and ethics to ensure they are living up to these goals (World Engineering Day, 2021). According to Kemp (2006), technological innovation can be a useful tool for achieving sustainable development. Therefore, making technology students aware of sustainability boundaries and tools is an important educational task for higher education. Developing sustainability competencies amongst graduates is particularly critical to the development of sustainability literacy and for students to become positive change agents in their workplace and personal lives (Sipos, 2008 in Cebrián *et al.*, 2019).

ENGINEERING EDUCATION FOR SUSTAINABLE DEVELOPMENT

Education for Sustainable Development (ESD) aims to train future leaders to become responsible managers of the common resources considering the environment, economics, and equity (Radhakrishnan, 2018). There is a consensus regarding the adoption of student-centred approaches to tackle engineering ESD: UNESCO declares that active learning methodologies foster the acquisition of the sustainable development competencies required to achieve the 2030 Agenda (UNESCO, 2021); Takala & Korhonen-Yrjänheikki (2019) state that collaborative learning, open dialogue, and innovation are at the heart of ESD; and Tejedor Papell *et al.* (2021) refer that challenge driven education can bridge engineering and sustainability. Specifically, in challenge driven education, students work on real-life and often real-time challenges affecting society and industry. The students address open-ended, ill-defined problems that can have multiple solutions to position ideas, innovations and decision making in the forefront of the learning process. Particularly, the design of sustainable solutions and exploration of alternatives requires sound scientific and technological knowledge as well as openness to innovative ideas. To explore as many possibilities as possible, the student is stimulated to research, plan, and debate, collaborating with and championing his/her team (Warburton, 2003).

The integration of ESD into engineering degrees contributes to the development of skills related to sustainability, such as critical and creative thinking, problem solving, capability to act, collaborative competence and systemic thinking (Segalàs & Sánchez-Carracedo, 2020). In this respect, Takala & Korhonen-Yrjänheikki (2019) identify as key engineering ESD competencies holistic understanding, communication and collaboration skills, ability and willingness for critical and reflective thinking, creativity, innovativeness, and entrepreneurship. Considering capstone programmes, Malheiro *et al.* (2019) propose the 4C2S framework to analyse the contributions made by a capstone programme to the critical professional competencies. These include thinking and problem solving, effective communication, collaboration and team building, and creativity and innovation— known as the four C—as well as socio-professional ethics and sustainable development-oriented practices—referred as the two S. 4C2S maps the aims, learning processes, and mandatory deliverables of capstone programs to the development of these six core competencies.

LEARNING FRAMEWORK

EPS was designed by Arvid Andersen in 1995 to prepare engineering undergraduates to become global professionals. This learner-centred programme adopts project-based learning, multicultural and multidisciplinary teamwork, and promotes learning autonomy and responsibility. The aim is to develop sound scientific and technical competencies together with interpersonal skills, such as intercultural and interdisciplinary communication and teamwork, preparing engineering undergraduates to work in international teams and solve multidisciplinary problems. The teams are always multicultural and multidisciplinary, guaranteeing interaction between four to six students from distinct cultures and fields of study. According to Arvid Andersen (2004), EPS prepares engineering students to work in a global environment, to co-operate, to communicate and to compete. EPS is currently offered by a network of nineteen universities, called EPS providers, located in twelve European countries (European Project Semester, 2022). This is the case of Instituto Superior de Engenharia do Porto (ISEP), which runs EPS in the spring semester for more than a decade.

The programme corresponds to 30 European Credit Transfer System Units (ECTU) distributed by six modules: Project Management and Teamwork (2 ECTU), Marketing and Communication (2 ECTU), Foreign Language (2 ECTU), Energy and Sustainable Development (2 ECTU), Ethics and Deontology (2 ECTU) and 20 ECTU assigned for the Project module. At the core of this framework is the Project module. It challenges teams to find innovative sustainability-driven solutions for real problems (Silva *et al.*, 2018).

Projects briefs always gravitate around sustainability. Regardless of the nature of the problem, all projects must follow ethics and sustainability-driven design and development practices. Nonetheless, multiple projects related to sustainability have been developed, mainly addressing food production, smart cities, and robotics. The teams must consider the ethical, social, economic, and environmental impact of the designed solutions, namely, in terms of resources, materials and components used in the prototype, product, packaging, production, logistics, and marketing.

ACADEMIC SUCCESS

The current analysis uses historical data from the cohort of 228 international engineering, business and design students who participated in EPS@ISEP between 2011 and 2021. These students were organized in 45 teams of four to six, comprising several nationalities, fields of study and Belbin team role profiles. The teams choose 45 project briefs addressing problems directly related to sustainability (58 %) as well as to other (42 %) areas (Table 1).

Table 1: Problems addressed by developed projects.

Problem Area	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Sustainability	0	2	2	2	4	3	3	3	3	3	1
Other	2	2	1	3	1	2	1	1	1	3	2

In the analysed period, two students did not complete the programme and, as such, were not classified, resulting in an overall success rate of 99 %. Figure 1 displays the grade histogram of the classified students (left) and the average project grade per problem area (right). The comparison between the average grades of EPS@ISEP (77 % ± 10 %) and ISEP students (71 % ± 7 %) on the sixth semester shows the higher achievement and motivation of EPS@ISEP students. The difference between the average grade of sustainability-related projects (79 % ± 5 %) and that of other projects (81 % ± 4 %) is not relevant.

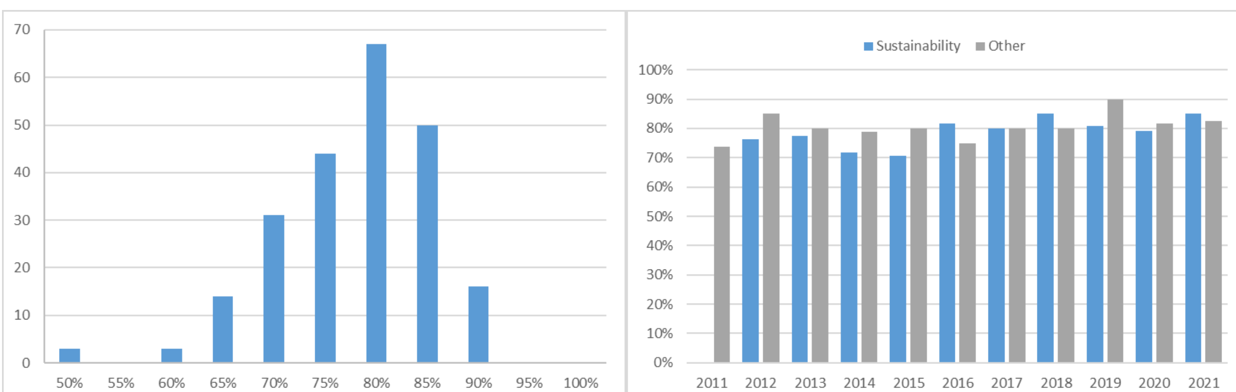

Figure 1: Individual grade histogram (left) and average project grade per problem area (right).

Finally, to determine the extent to which a project addressing a non-sustainability related problem follows sustainable design and development practices, the 4C2S analysis framework was applied to the Pet Tracker project developed in 2013. The results showed it fostered the desired 4C2S competencies in the team members, namely the much-sought combination of soft, hard, ethics and sustainability related skills (Malheiro *et al.*, 2019).

CONCLUSION

In EPS@ISEP, academic success and learning emerge from motivating and focusing on the learner. To do so, it adopts student-centred learning strategies; proposes real problems students relate with; exposes students to multicultural and multidisciplinary teamwork; and challenges students to find innovative solutions supported by ethical decision-making and sustainability-driven design.

The 4C2S capstone analysis framework, the achieved success rate and the grades obtained by the students attest that this combination promotes academic success, autonomous learning, and essential professional skills. Finally, this work suggests the need to identify and collect motivational indicators, namely to assess the influence on academic success of prior knowledge, cultural and personality traits as well as personal and professional projects.

ACKNOWLEDGEMENT

This work was partially supported by Portuguese National Funds through FCT – Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) – as part of project UIDB/50014/2020.

REFERENCES

Andersen, A. (2004). Preparing engineering students to work in a global environment to co-operate, to communicate and to compete. *European Journal of Engineering Education*, *29*(4), 549-558. doi:10.1080/03043790410001711243

Cebrián, G., Hernandez, A., & Segalas, J. (2019). Assessment of sustainability competencies: a literature review and future pathways for ESD research and practice. *Central European Review of Economics and Management*, *3*(3), 19-44. doi:10.29015/cerem.664

Duarte, A. J., Malheiro, B., Arno, E., Perrat, I, Fuentes, P., Guedes, P., Silva, M. F., Guedes, P., & Ferreira, P. (2020). Engineering Education for Sustainable Development: The European Project Semester Approach. *IEEE Transactions on Education*, *63*(2), 108-117. doi:10.1109/te.2019.2926944

European Project Semester. (2022). *Welcome | European Project Semester*. http://www.europeanprojectsemester.eu/

Fechheimer, M., Webber, K., & Pleiber, P. B. (2011). How Well Do Undergraduate Research Programs Promote Engagement and Success of Students? *CBE—Life Sciences Education, 10*(2), 156-163. doi:10.1187/cbe.10-10-0130

Haughery, J. R., Raman, D. R., Olson, J. K., & Freeman, S. A. (2019). Robots, Motivation, and Academic Success. *International Journal of Engineering Education 35*(6A), 1859-1871.

Kamp, L. (2006). Engineering education in sustainable development at Delft University of Technology. *Journal of Cleaner Production*, *14*(9–11), 928-931. doi:10.1016/j.jclepro.2005.11.036

Leal Filho, W., Shiel, C., & Paço, A. (2016). Implementing and operationalising integrative approaches to sustainability in higher education: the role of project-oriented learning. *Journal of Cleaner Production*, *133*, 126-135. doi:10.1016/j.jclepro.2016.05.079

Malheiro, B., Guedes, P., Silva, M. F., & Ferreira, P. (2019). Fostering Professional Competencies in Engineering Undergraduates with EPS@ISEP. *Education Sciences*, *9*(2), 119. doi:10.3390/educsci9020119

Martínez Casanovas, M., Ruíz-Munzón, N., & Buil-Fabregá, M. (2022). Higher education: the best practices for fostering competences for sustainable development through the use of active learning methodologies. *International Journal of Sustainability in Higher Education*, *23*(3), 703-727. doi:10.1108/IJSHE-03-2021-0082

Nylund, R. & Malheiro, B. (2022). Learning Engineering Ethics: The EPS Contribution. In B. Malheiro & P. Fuentes-Durá (Eds.), *Handbook of Research on Improving Engineering Education with the European Project Semester* (pp. 165-175). IGI Global. doi:10.4018/978-1-6684-2309-7.ch009

UNESCO. (2021). *UNESCO Engineering Report. Engineering for Sustainable Development: Delivering on the Sustainable Development Goals*. UNESCO. https://en.unesco.org/reports/engineering

United Nations. (1992). *Rio Declaration on Environment and Development*. Report of the United Nations Conference on Enviroment and Development (Annex I). https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf

United Nations. (2022). *Sustainable Development Goals*. https://www.un.org/sustainabledevelopment/sustainable-development-goals/

Radhakrishnan, B. D. (2018). Pragmatic Framework for Graduate-level Sustainability Capstone Projects. In *Proceedings of the 2018 American Society for Engineering Education Annual Conference & Exposition*, Salt Lake City, Utah (pp. 1-18). doi:10.18260/1-2--30879

Segalàs, J., & Sánchez-Carracedo, F. (2020). Education for Sustainable Development Goals in Spanish Engineering Degrees. In *Proceeding of the 48th Annual Conference of the European Society for Engineering Education* (SEFI 2020). European Society for Engineering Education, (pp. 1422-1424). http://hdl.handle.net/2117/329430

Silva, M. F., Malheiro, B., Guedes, P., Duarte, A., & Ferreira, P. (2018). Collaborative Learning with Sustainability-driven Projects: A Summary of the EPS@ISEP Programme. *International Journal of Engineering Pedagogy*, *8*(4), 106-130. doi:10.3991/ijep.v8i4.8260

Takala, A. & Korhonen-Yrjänheikki, K. (2019). A decade of Finnish engineering education for sustainable development. *International Journal of Sustainability in Higher Education*, *20*(1), 170-186. doi:10.1108/IJSHE-07-2018-0132

Tejedor Papell, G., Högfeldt, A. K., Segalàs Coral, J., & Gumaelius, L. (2021). Challenge driven education for sustainability in engineering. A White Paper. In *Proceedings of the 10th Engineering Education for Sustainable Development Conference*, EESD 2021. Cork: University College Cork, (pp. 495-502). http://hdl.handle.net/2117/347607

Warburton, K. (2003). Deep learning and education for sustainability. *International Journal of Sustainability in Higher Education*, *4*(1), 44-56. doi:10.1108/14676370310455332

World Engineering Day. (2021). *Do Engineers Have The Right Tools To Meet The UN Sustainable Development Goals?* UNESCO. https://worldengineeringday.net/2020/03/07/do-engineers-have-the-right-tools-to-meet-the-un-sustainable-development-goals/

York, T. T., Gibson, C., & Rankin, S. (2015). Defining and measuring academic success. *Practical Assessment, Research & Evaluation, 20,* 5. doi:10.7275/hz5x-tx03