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STUDENT PERSPECTIVES ON SUSTAINABILITY IN ENGINEERING EDUCATION: MULTIPLE CASE STUDY OF EUROPEAN BACHELOR'S PROGRAMS IN INDUSTRIAL ENGINEERING AND MANAGEMENT (RESEARCH)

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ABSTRACT

The global sustainability crisis is calling for engineers to take action. To enable and empower engineers to address this crisis, there must be a change in engineering education. Given the industry's key role in not only causing but also solving this sustainability crisis, it is especially crucial to improve how sustainability is addressed in industrial engineering and management (IEM) education. This paper examines (1) to which extent European IEM degrees are covering sustainability; (2) European IEM students' motivations to learn and work with sustainability topics; and (3) their perceptions of their degree's contribution to their knowledge and motivation regarding sustainability; and (4) which sustainability-related changes they would like to see in their degrees. Three IEM curricula covering different regions of Europe—Portugal, Germany, and Turkey—were analysed. The mixed-method analysis included a quantitative evaluation of the extent to which each course meets specific theory-based learning objectives pertinent to sustainability in engineering education. The analysis was complemented by students' perspectives, which were gathered through group discussions and interviews. The results reveal how sustainability is addressed in IEM education in different European regions, its impact on students' knowledge and motivation for sustainability issues, and how sustainability in engineering education should be developed based on students' perceptions. These findings contribute to the research on sustainability in engineering education and support university teachers in revising engineering study programs to provide adequate sustainability understanding and skills to students.

1 INTRODUCTION

As technological solutions and innovations are considered key to addressing the ongoing sustainability crisis, engineers play an important role in solving this crisis (Fitzpatrick 2017, 916–926; Pritchard and Baillie 2006, 555-565). However, Engineering Education in Europe has traditionally prioritised technical skills and knowledge, often neglecting the social, economic, and environmental dimensions of sustainability. To equip and motivate future engineers with the necessary knowledge and skills to design and implement sustainable solutions that can contribute to solving this crisis, a rethinking of the engineering curriculum and pedagogy is required.

To form a comprehensive big picture of the current state of sustainability in engineering education and complement the lacking extant research, it's important to consider multiple perspectives, including those of students, “whose capabilities and characteristics affect the reception of new views and are at the core in terms of achieving the sustainability goals” (Bask 2020). Given the industry's key role in the sustainability crisis, it is particularly relevant to improve how sustainability is addressed in industrial engineering and management (IEM) education. Thus, this research aims to provide engineering educators, particularly in IEM, insights into the development needs of the current curricula, based on the perspectives of IEM students at European Universities, enabling a pathway for more sustainability-oriented education of future engineers.

Stemming from the above-mentioned gaps, this paper aims to answer the following research questions: (1) to which extent European IEM degrees are covering sustainability; (2) European IEM students' motivations to learn and work with sustainability topics; and (3) their perceptions of their degree's contribution to their knowledge and motivation regarding sustainability; and (4) which sustainability-related changes they would like to see in their degrees.

The paper is structured as follows. In section 2, we briefly discuss the theoretical background and extant research gaps on sustainability in engineering education and its educational learning objectives. In section 3, we explain our methodological choices, i.e., how the mixed-method multiple case study of three IEM bachelor's programs in European universities was conducted. In section 4, the findings are discussed, and their contributions to research and practice are concluded in section 5; the findings will contribute to the research on sustainability in engineering education, and support university teachers in revising engineering study programs to provide adequate sustainability understanding and skills to students.

2 THEORETICAL BACKGROUND

Prior research on sustainability in engineering education has been interested in sustainability awareness (Azapagic, Perdan, and Shallcross 2005, 1-19), but has often centered on environmental sustainability, neglecting social and economic sustainability (Thürer et al., 2018). To educate engineers with the necessary sustainability-related skills, we need a more holistic view of the sustainability dimensions, extending beyond the environmental side of sustainability (Thürer et al. 2018, 608–617). Economic and social levers are critical in engineering; “so that changes in economic and social behaviours can complement and facilitate technological change” in moving humanity towards sustainability (Fitzpatrick 2017,

916–926). Therefore, this paper focuses on the improvement of how sustainability, in all its environmental, social, and economic components, is addressed in engineering education.

Research has recently grown to address the need for sustainability education in engineering fields such as chemical and environmental engineering (Azapagic, Perdan, and Shallcross 2005, 1-19; Glavič, Lukman, and Lozano 2009, 47-61). However, research focusing on the IEM field lacks comprehensive understanding. IEM reflects a mix of more traditional engineering studies, such as physical sciences, mathematics, manufacturing, but also social sciences as well as management, human factors, and business studies (Elsayed 1999, 415–421). Hence, the IEM perspective has a high potential to impact the implementation of sustainability practices in the industry.

We approach the research gaps by adopting the educational objectives for Engineering for Sustainable Development (ESD; Quadrado 2013). According to Quadrado (2013), sustainable development is pursued through education by: (i) developing student awareness of issues in areas of sustainable development; (ii) exploring and demonstrating the role and impacts of various aspects of engineering (technology, design, process, materials, etc.) and policy decisions on environmental, societal and economic problems; and (iii) equipping students with engineering and decision-making tools and methodologies and providing them opportunities to apply them on issues related to sustainable development. These objectives were used as the foundation to establish a research framework for analysing sustainability in engineering degrees, which is further explained in the next section.

3 METHODOLOGY

We apply a multiple case study of three carefully selected IEM study programs across European universities. Each of the cases was analysed by a local student to allow a full understanding of the case context. We employed a mixed-methods approach, which allows the investigation of particular educational phenomena with great depth and breadth (Almalki 2016, 288-296), hence permitting us a comprehensive understanding of the curricula and their ESD coverage, while also gathering valuable qualitative insights from local students and graduates.

The research process unfolded in four steps. In the first step, we sampled a range of curricula cases to represent different regions in Europe. During the case sampling, we chose IEM study programs that would assist us in taking into account the contextual and geographical diversity within Europe, as well as convenience sampling (Etikan, Musa, and Alkassim 2016, 1-4). The selection resulted in having one case study program from each of the following Universities: Bilkent University (Ankara, Turkey), University of Porto (Porto, Portugal), and Technical University of Kaiserslautern (Kaiserslautern, Germany).

To address particularly research question 1, a quantitative analysis was performed in the second step to evaluate the degree to which each course followed the objectives of engineering for sustainable development as outlined by Quadrado (2013). The courses were rated on an integer scale ranging from 0 (objective not addressed) to 3 (objective fully addressed). The primary data source for this step was the course

descriptions in the Universities' course catalogs. When the available data was perceived insufficient, we sourced secondary data from students who took the course recently and/or professors of the respective courses.

In the third step, we shifted to the qualitative part of our research to further explore the students' perceptions on sustainability in IEM curricula. We organized three workshops to engage with local students and recent graduates to gather their input and perspectives on the case curriculum they are/were studying and how it addresses sustainability (one per University). During the workshops, the students were asked to rate themselves on a 10-step Likert scale, to self-evaluate how much they agreed or disagreed with 13 statements. Follow-up discussions, and open-ended questions related to research question 4, were initiated to profoundly understand students' viewpoints, and workshop memos written. The presented statements aimed to gather insights mainly to the research questions 2 and 3, and covered topics such as students' motivation to learn about sustainability and pursue a career in this field, and how students perceive the contribution of their degree to their knowledge and motivation regarding sustainability. A total of 18 students participated voluntarily, without external incentives, in the workshops, with 7 students from the University of Porto, 7 students from the Technical University of Kaiserslautern, and 4 students from Bilkent University. In the final and fourth step, the findings from the within-case analysis were compared in cross-case analysis to detect relevant differences and similarities between the cases.

The research quality was ensured with multiple tactics, such as data and researcher triangulation.

4 RESULTS

4.1 Degrees' profiles and sustainability coverage

Bilkent University (Turkey)

Bilkent University's chosen Bachelor program is named "Industrial Engineering", or, in Turkish, "*Endüstri Mühendisliği*", coordinated by the Industrial Engineering Department. In 2019, a curriculum revision resulted in new energy and sustainability-related elective courses. The range of elective options, and senior projects, in which students concentrate on issues facing businesses today, are considered the curriculum's differentiators. Additionally, renewable energy and sustainability have recently become prominent in graduation projects.

Technical University of Kaiserslautern (Germany)

For the Technical University of Kaiserslautern, the IEM Bachelor programme with a focus on civil engineering, named officially "*Betriebswirtschaftslehre mit technischer Qualifikation im Bauingenieurwesen*", which translated to "Business Studies with technical qualification in civil engineering", will be analysed in this paper. The main department responsible for the IEM programmes is the economics department. In 2021's curriculum revision, the only mandatory sustainability course was deleted, and 2 elective courses were introduced, but sustainability has nevertheless gained general traction in education.

University of Porto (Portugal)

The “Bachelor in Industrial Engineering and Management”, or, as officially named, “*Licenciatura em Engenharia e Gestão Industrial*” is the degree analysed from the University of Porto. This degree has a strong focus on Mechanical Engineering, doesn’t offer any specialisations, and the elective courses are very limited. The degree coordination is under the Department of IEM. In 2021, the University of Porto's IEM program separated the existing integrated master's program into a bachelor's and master's program, but no changes were introduced regarding how sustainability is approached. Currently, teachers incorporate specific sustainability-related themes into their courses' curriculum on their own; however, there aren't any standards or criteria for doing so.

These 3 degrees were analysed based on the extent to which each of their courses covers each of the educational objectives for ESD, as explained in the methodology section. The results of this analysis are presented in Table 1, in percentage to ease comparison.

Table 1. Quantitative analysis of the coverage of ESD objectives in the selected case IEM degrees

	Objective	Development of student awareness of issues in areas of sustainable development				Exploration and demonstration of the role and impacts of various aspects of engineering and policy decisions on environmental, societal, and economic problems				Equipping students with engineering and decision-making tools and methodologies and providing them opportunities to apply them on issues related to sustainable development.				Total courses
		Rate	0	1	2	3	0	1	2	3	0	1	2	
Bilkent	Mandatory	69%	25%	3%	3%	66%	22%	9%	3%	75%	16%	6%	3%	32
	Elective	62%	33%	0%	5%	62%	24%	10%	5%	62%	19%	14%	5%	21
Kaiserslautern	Mandatory	65%	18%	18%	0%	71%	24%	6%	0%	71%	24%	6%	0%	17
	Elective	75%	6%	6%	13%	75%	6%	6%	13%	75%	6%	6%	13%	16
Porto	Mandatory	60%	33%	7%	0%	63%	27%	10%	0%	67%	20%	13%	0%	30
	Elective	78%	0%	11%	11%	78%	0%	11%	11%	56%	22%	11%	11%	9

It is apparent that the ESD objectives are barely addressed in the case degrees. Still, Kaiserslautern appears to meet these objectives to a slightly greater extent than the other degrees. We can also observe that the objectives are slightly more addressed in elective courses rather than mandatory ones.

4.2 Students’ motivation to learn about sustainability and pursue a sustainability-related career at the beginning of their professional lives

According to the findings, students across all three universities display a strong motivation to learn about sustainability, with Bilkent students being the most motivated (scores 8-10). These students perceive sustainability to be an increasingly important topic in their future personal and professional lives.

Students' motivation to contribute to addressing sustainability and prioritizing companies with sustainability commitments at the beginning of their careers was rated similarly among students from the same university. Bilkent and Kaiserslautern

students demonstrated a positive inclination towards both topics, while most Porto students had negative scores. Bilkent students are motivated to work on sustainability issues because they associate it with working for a reputable company, which they believe is more likely to have established sustainability commitments and provide higher earnings. Conversely, Kaiserslautern students had varying levels of motivation, as some perceived sustainability as a top priority, while others viewed it only as a desirable attribute. The variation seemed to stem partly from the different awareness levels in their earlier educational path. Most Porto students choose to prioritize personal financial well-being over sustainability in their entry-level positions. They believe that they can have a greater impact on sustainability as citizens rather than in their first jobs and perceive obtaining a first job with a sustainability focus as extremely challenging.

Bilkent students expressed high levels of confidence in working with sustainability topics after graduation, scoring a 7. This result was mostly influenced by the fact that one professor was promoting his/her sustainability-related work project in a class. Kaiserslautern students, however, scored lower (between 4 and 5), due to a lack of confidence related to all career paths, which they believe is a result of a strongly theoretically-based education. In Porto, the students who scored lower (between 4 and 5) tended to be females and mentioned that sustainability was not given sufficient emphasis in Porto's courses, often being addressed solely as an afterthought. Contrarily, students with higher scores (between 8 and 9) stated that the degree prepares them for any career, including sustainability-related ones.

4.3 Students' perspectives on the contribution of their degree to their motivation and knowledge regarding sustainability

Although students' motivation to learn about sustainability is high, the scores were generally low for the extent to which their courses contributed to their motivation (1-4). Kaiserslautern students considered their courses to motivate them slightly more than the other universities thanks to a sustainability course, which used to be mandatory but is now elective since 2021. One student scored a 9 due to choosing a sustainability-oriented thesis topic.

The students' self-perceived level of general knowledge on sustainability is moderate (majority between 5-6). In Porto, the younger students had lower scores (1-4). On the other hand, when asked about their level of IEM-related sustainability knowledge, most students, regardless of their university, rated themselves with significantly lower scores (1-2). Meanwhile, older students scored slightly higher, indicating that their accumulated time in university studies equips them with more knowledge, whether it's generated at the university or outside of it.

The students' perceptions of whether their degrees equipped them with relevant knowledge and skills to work on sustainability projects in the future varied. Bilkent students believed that the courses focused on developing general soft skills rather than sustainability. Kaiserslautern students agreed that the updated degree did not guarantee relevant sustainability knowledge and offered professional sustainability skills to a varying extent (scores varying from 1 to 6). The variation can be explained by the different technical backgrounds of the students. Porto students highly disagreed that their curriculum ensured relevant knowledge on sustainability, with mixed opinions

on relevant skills. Gender differences were noted here, with mostly men scoring higher and claiming that the degree prepared them for any activity related to the IEM field, including those involving sustainability, while others believed that despite the degree's broad scope, it did not provide them with the necessary skills to address sustainability issues.

The majority of students agreed that they have the need to seek additional resources to acquire relevant knowledge for sustainability-related projects (scores ranging from 6 to 9). However, when asked about the need to seek additional resources to acquire relevant skills, the answers were more varied. Bilkent students expressed an even greater need for external resources for developing relevant skills. In contrast, Kaiserslautern and Porto students provided a wide range of responses, with some stating that their degree already equipped them with general skills that could be applied to sustainability-related work, while others argued that more specific skills were necessary and not being provided, hence the need to turn to external sources.

Most students had low or no expectations at all towards their curricula addressing sustainability when they started the selected bachelor, with the exception of a few students from Porto who had higher expectations due to their higher exposure to sustainability in some of their extracurricular activities during high school.

Finally, the majority of students across all universities expressed dissatisfaction with the current level of sustainability integration and desired more incorporation of sustainability in their courses. Yet, a few students from Porto were satisfied with their degrees as such, saying that although their degree program did not have a significant emphasis on sustainability, it provided them with adaptable skills to handle diverse situations.

4.4 Desired changes in IEM sustainability education from students

Students expressed a general desire for greater emphasis on sustainability throughout their degrees. To achieve this, the students suggested incorporating sustainability into more courses, creating new courses that specifically address sustainability, and offering project-based opportunities to apply sustainability-related knowledge. The students from Kaiserslautern recommended that at least one mandatory course be dedicated to sustainability, while those from Porto mentioned that such a course could cover potential sustainability careers. Finally, the students from Porto suggested inviting guest speakers for lectures to help achieve these goals.

5 CONCLUSIONS

Our findings contribute to the research and practice on sustainability in engineering education by showing that sustainability is still poorly addressed in European IEM degrees despite the region. Despite this, students are generally motivated to learn about sustainability and contribute to addressing sustainability challenges in their future careers, although this is not seen as a priority for everyone and is perceived differently depending on students' views on sustainability work in their countries. The courses' contribution to students' sustainability knowledge is perceived as very low, while the contribution to developing relevant skills to work on sustainability projects varies among students. Most students feel the need to resort to external sources to

learn about sustainability, but not necessarily to develop skills. Despite not having high expectations towards sustainability when they started their studies, students express dissatisfaction with the extent to which sustainability is being addressed in their degrees. Students suggest, for example, higher incorporation of sustainability in all courses and the implementation of courses in different formats.

These insights contribute to research by providing a new understanding of the state and directions for integrating sustainability into engineering education in Europe, not only from an environmental sustainability perspective but holistically (Thürer et al. 2018, 608–617), targeting particularly industrial engineering and management (Elsayed 1999, 415-421) educators. Meanwhile, the research provides practical contributions for the teachers in engineering education: our findings can support professors in the attempt to design more sustainability-oriented curricula by providing professors with relevant insights on their students' perspectives.

Even though just three degrees have been studied and a limited number of students participated, this study is an important early step into exploring sustainability in engineering education, and made it possible to identify some interesting perspectives that can serve as a basis for further investigation. An intriguing finding is the contrasting views that Turkish and Portuguese students have on the financial rewards of sustainability-related work, as Portuguese students express not wanting to prioritize companies with big sustainability commitments at the beginning of their careers due to the importance they place on earning a higher salary, whereas Turkish students associate working on sustainability issues with working for a reputable company and earning a higher salary. Another intriguing observation is the students' dissatisfaction with the insufficient attention given to sustainability in their degrees, as they mention having no or low expectations that their programs would cover sustainability issues when they initiated their studies.

Given the interesting findings of this research, there are several directions that future investigations could take. Firstly, expanding the research scope to include a larger number of students and degrees, both from the same countries, to draw more accurate country-specific conclusions, and from other countries to further understand how students' perspectives change across the different European regions. The dissemination of a survey among a larger pool of European IEM Students could be beneficial for this purpose, as it would help validate the findings and reduce potential biases from researchers' interpretations, or students not fully understanding the sentences which they were asked to rate or the discussions. Considering the wide range of students' perspectives on the coverage of relevant competencies for working on sustainability-related projects within IEM programs, another topic of interest would be to explore which skills students consider relevant to work in such a project and how these can be integrated into IEM degree programs. Finally, continuing the ongoing investigation on how sustainability can be addressed in IEM programs without compromising the program's core content is of the utmost importance to tackle the dissatisfaction expressed by the students.

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