

Using the Learning Factory for the Integration of Sustainability in the Engineering Curricula in Higher Education

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Abstract. Sustainability, gaining prominence due to perpetual population expansion and rapid depletion of resources, emphasizes economic prosperity, environmental conservation, and social equity. Students in higher education, especially those in engineering disciplines, play a pivotal role in the adoption and implementation of sustainability principles in, both, business and society. Within this context, the systematic integration of sustainability into engineering education is of paramount importance, thus helping to provide the students with awareness of the socio-economic and environmental aspects of sustainable development in addition to improving their technical skills. However, the process of embedding sustainability in the curriculum of higher education faces challenges from various stakeholders, including students, educators, and the higher education institution. The attitudes of students toward the subject, educators' proficiency in sustainability, and the institutional frameworks' support (or lack thereof) for this integration are some of the prominent challenges. Learning factories, serving as educational platforms that simulate real production environments and bridge academia with industry, emphasize competency development, facilitating participants in acquiring in-depth knowledge about industrial practices. In this research, the authors delve into the potential of learning factories as a platform to overcome the challenges faced during the sustainability integration process in higher education curricula, and to help foster students' competency development. A literature review was conducted to thoroughly investigate the challenges of integrating sustainability into higher education. Based on these findings, a comprehensive framework is presented, highlighting how learning factories can address these challenges and enhance students' competency development.

Keywords: learning factory, higher education, sustainability, competencies development.

1 Introduction

Higher Education Institutions (HEIs) act as transformative agents by shaping the mindsets and values of future leaders in academia, business, and the various engineering disciplines. HEIs are essential in advancing sustainable development and preparing professionals to embed environmental, social and economic aspects in systems and

infrastructure. HEIs, especially in the field of engineering by its nature, need to adopt a holistic and hands-on approach in promoting the aspects and impacts of the triple-bottom-line of sustainability – Environmental, Social, and Economic.

One of the possible ways to enhance the teaching and learning of sustainability is to use learning factories (LFs) as a platform to incorporate business practices into the educational process. LFs are environments where learners are exposed to all learning support facilities in a dynamic way, and where they can mix theoretical knowledge with practical skills. Engineering education needs adequate teaching methods and learning environments to address the challenges of sustainable production. Otherwise, students will not be able to develop useable competencies and merely accumulate theoretical knowledge [1]. LFs introduce students to the complexities of implementing sustainable solutions in real-world business scenarios by placing sustainability in the concrete context of business practices. This direct exposure helps learners understand the vital intersection between sustainability principles and business operations, making the learning experience more relevant and applicable. LFs play a crucial role in enhancing learners' sustainability competencies, essential for solving real-world problems and performing tasks, by integrating knowledge, skills, and behaviors [2]. This integration bridges the gap between theory and practice in sustainability. Moreover, the primary distinction of LFs is their emphasis on hands-on learning, significantly contrasting with passive, lecture-based methods and surpassing traditional aids like images and videos.

LFs need to be aligned with the curriculum objectives and learning outcomes of education in sustainability, and to provide appropriate assessment methods and feedback mechanisms [1]. Therefore, LFs can be seen as a promising platform to integrating sustainability into higher education curricula, especially in engineering disciplines, where authenticity and task relativity are crucial for effective learning. This paper aims to identify the challenges involved in integrating sustainability into higher education curricula, and to explore how LFs can serve as effective platforms to overcome these challenges.

2 Literature Review

2.1 Sustainability in Higher Education Curriculum

Sustainability can be defined as a multidimensional paradigm that encapsulates the synergistic amalgamation of economic growth, environmental protection, and social well-being [3]. From an engineering standpoint, the aim of sustainability is to minimize the environmental and societal impacts of economic activities through the optimization of resource usage, maximization of energy and material efficiency, and cost-effectiveness of processes [4].

Different disruptions are taking place at global level which necessitate taking active measures right from educating the students from the beginning to bringing changes in the professional fields. To cater for sustainable development in education, it is imperative to bring requisite changes in the curriculum for the concept and agenda of sustainable development are promoted right from the beginning [5]. This complex and diverse topic requires an interdisciplinary approach and understanding. HEIs are increasingly

embedding sustainability into their curricula to enhance sustainability literacy through strategies such as updating existing courses, creating specialized degrees, and engaging in sustainability research and projects [6]. As such, HEIs have a major responsibility to engage with community inclusion and development to be able to bring about that change [7].

2.2 Challenges for Integrating Sustainability in the Higher Education Curriculum

The authors conducted a thorough literature review on the challenges faced while integrating sustainability into the HEIs curriculum. The databases were searched included Web of Science and Scopus, with keywords such as higher education, sustainability, and curriculum. Selecting studies mainly from 2013 to 2023, authors applied a two-stage screening of titles, abstracts, and detailed content, choosing 29 articles that offered diverse, comprehensive insights into the challenges of this integration across various locations and engineering fields. To further this research, the authors have scrutinized the relevant literature to determine which of these challenges could be addressed by LFs and how they could potentially provide solutions.

Integrating sustainability into HEIs curriculum practices is fraught with challenges. One of the main difficulties in integrating sustainability into curriculum practices is the lack of knowledge and awareness about the complex and diverse aspects of sustainability among both educators and students [8]. The engineering curriculum, already dense with technical and specialized contents such as thermodynamics, materials science, and digital systems design, which makes it hard to accommodate interdisciplinary topics such as sustainability, and the existing disciplinary boundaries within the education system may also obstruct its integration [9]. Another significant challenge lies in the need to create practical and experiential learning aspects that can accommodate hands-on, project-based learning experiences, which are essential for highlighting the multifaceted nature of sustainability [10]. Another challenge is how to measure the learning outcomes of sustainability, which is a complex and multifaceted topic [11]. The challenges in the implementation of sustainability into curriculum practices are summarized in Table 1.

Table 1. Challenges for integrating sustainability into HEIs curricula

Challenge	Description	Grouping Category
Institutional Support	Lack of supportive institutional resources and policies [12, 13].	High Severity and Institutional Responsibility
Interdisciplinary Approaches	The need for a cross-disciplinary perspective in a traditionally siloed field [5, 12].	
Curriculum Integration	Difficulty lies in the cross-disciplinary nature on sustainability education [9, 12].	
Engineering-Specific Sustainability Content	Difficulty integrating socio-economic and environmental principles in engineering [14].	Moderate Severity. Faculty and Curriculum Design Responsibility
Faculty Engagement	Difficulties to hire and retain active, trained, and supported faculty [9, 12].	
Assessment Methods	Lack of suitable methods to assess complex sustainability-related outcomes [15].	

Curriculum Overcrowding	The challenge of adding sustainability topics without displacing others[9, 12].	Moderate Severity and Curriculum Design Responsibility
Student Engagement	Difficulty in engaging students in transformative sustainability learning[5, 15].	Lower Severity. Faculty and Student Engagement Responsibility
Practical and Experiential Learning	Challenges implementing practical, real-world, project-based sustainability learning [10].	Lower Severity and Board Practical Implementation Responsibility

3 The Use of Learning Factories to Overcome the Challenges

LFs play a crucial role in developing competencies necessary for addressing real-world sustainability challenges [16]. LFs prepare learners for industrial challenges and encourage interdisciplinary collaboration, benefiting students from various backgrounds and disciplines [7]. LFs are increasingly being harnessed to deliver education on sustainability, serving as contemporary platforms for imparting vital knowledge and skills in this critical area. According to [17], although LFs are employed worldwide to impart education on sustainability and the circular economy, their focus is primarily on the production phase of the life cycle, with the stages of product development, usage, and end-of-life receiving comparatively less attention. LFs support learners to develop their competencies for sustainability in a real-world setting, while overcoming some of the barriers and challenges that hinder the incorporation of sustainability into curriculum practices. In the following, a detailed examination is presented on how LFs address and reflect the challenges identified through literature review.

- **Institutional Support:** Securing institutional support for LFs and sustainability education necessitates showcasing their benefits in bridging theoretical learning with practical application, boosting employability, and advancing sustainability goals. Demonstrating success stories and tangible educational outcomes can persuade institutions to dedicate resources and support for these initiatives.
- **Interdisciplinary Approaches:** Another benefit of LFs is its multidisciplinary design [18], which breaks down traditional academic borders. This encourages an interdisciplinary dialogue that is necessary to understand the complex issues surrounding sustainability [2] and makes sure that solutions are developed from a comprehensive perspective rather than a narrow one.
- **Curriculum Overcrowding and Curriculum Integration:** By blending theory with hands-on application, these environments allow for a more efficient and consolidated approach to teaching [19]. Instead of segmenting theoretical lessons from practical exercises, LFs facilitate simultaneous understanding of both, streamlining content delivery. With the project-based nature inherent to this setup [1, 20], students can combine sustainability with other engineering subjects within a single effort, allowing them to optimize time and resources.
- **Engineering Specific Content:** LFs present an environment where traditional engineering principles can be interwoven with sustainability concepts. This fosters a holistic approach, empowering students to engineer solutions that are not only technically efficient but also socio-economically and environmentally conscious [7].

- **Faculty Engagement:** LFs can significantly enhance faculty engagement by providing a practical context for teaching and research in sustainability. They enable faculty to integrate real-world challenges into their curriculum, making education more interactive and impactful. Through LFs, faculty members can engage in collaborative projects with students, fostering a hands-on learning environment that not only benefits their teaching but also their professional development.
- **Assessment Methods:** LFs have the capacity to employ innovative assessment methodologies, departing from conventional and often constrained evaluation metrics [2]. Such experiential, and outcome-oriented assessment methodologies [21] and evaluation tools [22], which center on real-world problem-solving skills, and tangible project outcomes, can provide a more holistic view of a student's competency, ensuring that their grasp on sustainability concepts is both theoretically sound and practically applicable.
- **Practical and Experiential Learning:** One of the salient features of LFs is the experiential learning they provide [23]. LFs provide a platform where students can engage in practical experiences that mirror current industry standards, thereby overcoming the challenge of connecting theory with practical application. This experiential approach streamlines the development of practical skills and fosters an environment where learning is augmented through active participation, thus bridging the often-encountered gap between classroom learning and real-world practice.
- **Student Engagement:** LFs, by mimicking real-world scenarios, can offer students the opportunity to immerse in hands-on practices [19], transforming theoretical knowledge into tangible experiences, and also turn students into active participants who work together, solve problems, and generate creative solutions to real-world sustainability challenges, rather than passive consumers of theoretical knowledge.

4 Integrating Sustainability in the Curriculum of Engineering Higher Education

In developing a context-specific structure for infusing sustainability into curriculum practices within HEIs, seven crucial steps are discerned (Figure 1). Each of these steps is grounded in an extensive range of academic literature [9, 15]. Pathways Identification focuses on understanding an institution's current sustainability practices and gaps, emphasizing the role of Sustainable Development Goals (SDGs) in higher education. It requires leadership to use audits and alignment strategies to assess and guide sustainability efforts. The subsequent step, Stakeholder Engagement unites staff, faculty, and students in sustainability efforts, driven by coordinators to promote cross-departmental collaboration and begins when gaps are identified. Following this, the Adaptive Education phase comes into focus, highlighting an adaptable mindset and experiential Education for Sustainability. The fourth step, Integration into Curriculum, emphasizes the urgency of intertwining sustainability into the institution's educational offerings. The Promotion of Sustainability Awareness focuses on using social media, workshops, and seminars to enhance sustainability in engineering curricula, ensuring actionable steps and broad outreach to increase

students' sustainability awareness. Measurement and Evaluation constitute the sixth step, with the academic discourse underlining the significance of a general matrix for merging sustainability and the employment of evaluation platform for effective appraisals. The concluding step, Continuous Improvement and Scaling, emphasizes making necessary modifications post-evaluation and escalating sustainability efforts grounded on practices at other institutions. This comprehensive framework addresses all facets of integrating sustainability into curriculum practices, providing a robust foundation for the enhancement of sustainability in HEIs.

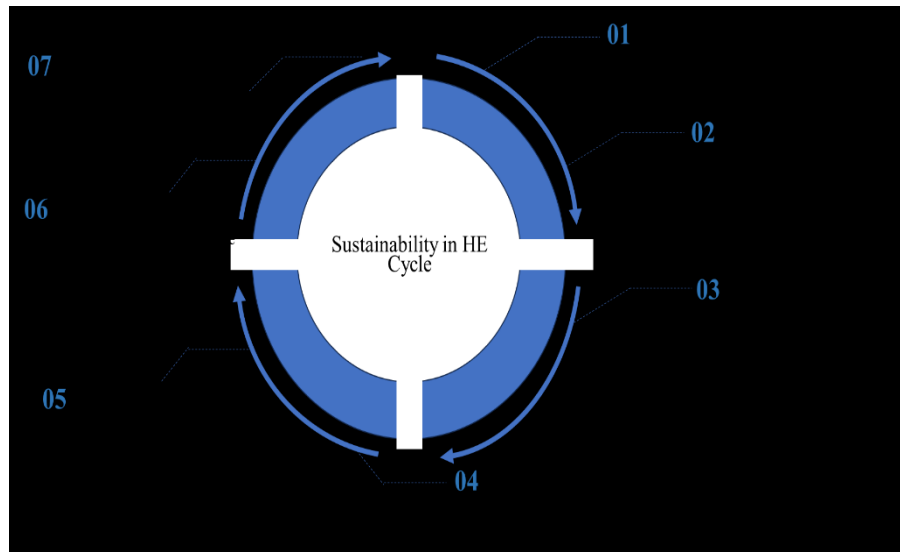


Figure 1. Sustainability in HE cycle

LFs, with their unique features that can overcome the challenges described in Section 3, can contribute to the framework designed for integrating sustainability into the curricula of HEIs. In this integration process, LFs can leverage their unique attributes, such as dynamic simulation, modeling, interdisciplinary environments, applied learning opportunities, and real-world industry scenarios, to provide a profound impact on every phase of the educational process. LFs encourage students, faculty, and staff to embrace a holistic approach to sustainability by merging theoretical concepts with real-world applications and exploring sustainability practices beyond their disciplines, thereby expanding the consciousness and practices of sustainability while integrating this new knowledge into their teaching processes, leading the way in adopting an interdisciplinary approach in education [7]. Furthermore, LFs offer the necessary assessment methods and performance measurement tools such as knowledge tests and simulated problem scenarios [23] for monitoring and evaluating sustainability competencies. In the continuous improvement and scaling phase, LFs refine educational practices and enhance the sustainability aspect of curricula by comparing outcomes between different student groups (e.g., those who have participated in LF trainings and those who have not), further solidifying the curriculum's focus on sustainability. LFs play a pivotal role

in the theoretical and practical integration of sustainability in engineering education. LFs also come with some challenges such as the initial investment and maintenance costs to the need for continuous faculty training and curriculum development. Therefore, these challenges should be considered when using LFs in sustainability education.

5 Conclusions

In this paper, the authors highlighted the growing importance of sustainability in response to population growth and resource depletion with emphasis on its key pillars, economic prosperity, environmental conservation, and social equity. The particular focus is put on the role of engineering students in promoting sustainability in business and society. However, integrating sustainability into higher education faces challenges from various stakeholders, including students, educators, and institutions. In this research, the potential of LFs as educational platforms to overcome these challenges and enhance students' competency development is explored. As a response, the authors proposed a comprehensive framework consisting of seven crucial steps to infuse sustainability into engineering curriculum practices in higher education institutions. These steps range from identifying pathways and engaging stakeholders to measuring and evaluating sustainability outcomes and ensuring continuous improvement and scaling. The proposed framework serves as a foundation for enhancing sustainability in engineering higher education. Integrating LFs into sustainability education and implementing the proposed framework might encounter several anticipated barriers. These include the substantial initial investment and ongoing maintenance costs associated with setting up LFs, the imperative for continuous training of faculty to stay abreast of evolving sustainability concepts, the presence of resistance among faculty members to modify established curricula. The authors recognize importance of validating effectiveness of the proposed framework that will be undertaken in conjunction with universities, colleges, and further education institutions involving different stakeholders as a way forward. In future research, the validation of the framework presented in figure 1 and utilizing LFs to overcome challenges can be conducted by measuring the sustainability awareness and competencies of student groups who receive sustainability education over a semester or academic year, using this framework and LF, compared to those who do not.

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2024-07-11

Springer

https://doi.org/10.1007/978-3-031-65411-4_40

Afy-Shararah M, Syed JM, Sahin O, et al., (2024) Using the learning factory for the integration of sustainability in the engineering curricula in higher education. In: Learning Factories of the Future: Lecture Notes in Networks and Systems, Volume 1059, Proceedings of the 14th Conference on Learning Factories (CFL 2024), 17-19 April 2024, University of Twente, Netherlands, pp. 337-345