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Integrating Circular Supply Chains into Experiential Learning: Enhancing Learning Experiences in Higher Education

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Abstract: This work integrates the circular economy (CE) into experiential learning in higher education, focusing on industrial and systems engineering. It addresses the need for suitable learning experiences and pedagogical strategies to enhance CE and sustainability education in active learning research. Accordingly, this study proposes integrating Kolb's experiential learning cycle with the ADDIE model into an instructional design framework for reflective and active engagement in learning activities within realistic circular supply chain scenarios. The methodology demonstrates this framework through a case study of an undergraduate module for CE problem-solving, focusing on waste reduction within small and medium enterprises in Mexico City. Based on student surveys and achievement metrics, results show positive student feedback and evaluation results, meeting module targets. This work's main contribution offers a framework for creating novel experiential learning cases and cultivating sustainability-related and disciplinary learning outcomes. It also recognises valuable links for citizenship commitment, problem-solving, community engagement, and CE education. However, this work acknowledges limitations in complex problem-solving difficulties, a resource-demanding nature, restricted transferability, and the limited evaluation of learning effectiveness. Future research will explore this work's relevance across Kolb's learning styles and diverse industries, focusing on student interest and motivation, and evaluating its impact on student outcomes in various educational contexts.

Keywords: circular economy; educational innovation; engineering education; experiential learning; supply chain management

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1. Introduction

This research-to-practice work refers to circular economy (CE) learning experiences in higher education—specifically in industrial and systems engineering—to provide learners with pertinent and engaging activities for their learning outcome development. This view links to the need to provide sustainability education for future professionals in the discipline. Hence, this work offers a pedagogical alternative for learning experience instructional design based on experiential learning, which might support educators in their particular academic settings.

The contribution of industrial and systems engineering to more bearable and efficient resource use is exemplified through supply chain management (SCM). This idea is based on the systemic contributions of supply chain operations to solid waste generation and other adverse sustainability effects such as carbon footprint, energy use, and increased traffic congestion in goods transportation and distribution. A supply chain is a linked network of suppliers, production facilities, and distribution centres that deal with logistics, production, distribution, and delivery processes on which materials and products flow upstream and downstream [1–3]. Accordingly, SCM is at the core of gaining a competitive advantage through efficient operations [4]. However, the need to address resource scarcity and environmental issues leads towards the inclusion of CE requirements in SCM [5]. The CE aims to achieve zero waste by (re-)circulating resources through biological cycles (such as natural decomposition) and technical cycles (including reuse, remanufacturing, refurbishing, and recycling), thereby overcoming the extraction–consumption–disposal logic of the linear economy [6]. Moreover, the CE has recently been proposed as a new perspective for socio-economic development and a promising foundation for achieving the Sustainable Development Goals (SDGs) [7]. The CE concept is crucial to address the environmental challenges posed by traditional linear economic models. This perspective aims to create a regenerative and sustainable approach to economic activities by promoting resource efficiency usage, waste reduction, and closed feedback loops.

Consequently, different stakeholders such as companies, universities, institutions, and civil society have called to contribute to the supply chains' transformation towards a circular configuration. However, despite the relevance of the CE, there is a gap between research and CE practice for SCM [5]. There is also pending work to include CE concepts in higher education programmes and courses [8,9].

One critical aspect of transitioning to a CE is to provide relevant and impactful education for this purpose. Understanding how to reduce difficulties in offering pertinent education in CE is vital for fostering a skilled and knowledgeable workforce—and citizens—capable of driving sustainable practises. By obtaining relevant education in CE for supply chain design, future professionals can identify opportunities for resource recovery, recycling, and reusing materials, leading to a reduced environmental impact and greater resource security [9,10]. Moreover, educating future professionals on the CE for supply chain design can promote industry-wide adoption, accelerating the shift towards sustainable practises.

Higher education institutions (HEIs) are pivotal in leading the transition towards a CE in line with SDG #4 Quality Education and SDG #12 Sustainable Consumption and Production [9,11,12]. To achieve this, it is essential to provide learning experiences that facilitate reflective practice and active engagement with real-life developments [13–15].

However, there is still a pressing necessity to develop effective pedagogical designs that enrich learning in higher education, particularly in SCM, with CE and other sustainability elements [9,16–20]. In this sense, there is a research gap in engineering education as, in general, there is no systematic and strategic integration of sustainability topics among degree programmes [21]. Moreover, there is a need to develop suitable approaches for integrating sustainability into the curricula and adopt tools for supporting students' exposure to sustainability issues and their active learning [13].

Thus, this work's research problem definition is twofold: on the one hand, it is necessary to identify appropriate learning experiences related to circular supply chains that enhance sustainability education, and second, it is crucial to determine and implement pedagogical strategies that can effectively bring these learning experiences to life.

Accordingly, it is necessary to adopt CE concepts in academic programmes beyond theoretical notions to engage students in hands-on supply chain redesign to achieve a zero-waste generation. As suggested by Del Vecchio et al. [22], experiential learning activities can develop the necessary competencies and mindset towards the CE. According to Kolb [6], experiential learning refers to knowledge construction through experience transformation, involving reflective thinking and active engagement. It is claimed that experiential learning enables students to understand their learning deeply, why they are participating in it, and how to apply their learned concepts to practical experiences in real-world scenarios [23,24].

The SCM discipline is commonly linked to industrial engineering programmes in Higher Education. The BSc in Industrial and Systems Engineering is one of the most popular undergraduate programmes, as the labour market highly appreciates it because of its professional versatility across industries and business sectors [25]. In general, as industrial engineering education involves complex subjects from different disciplines, an experiential learning approach can engage students in solving complex realistic problems whilst encouraging them to take responsibility for their education [26,27].

Therefore, this work addresses the importance of engaging industrial and systems engineering students towards the CE by designing circular supply chains in reflective and active learning settings. Hence, the research aim of this work is to create an instructional design framework supporting this approach and illustrate its application with a case study. By equipping engineering students with the competencies necessary to adopt circular principles through experiential learning, we can promote innovation, conserve resources, mitigate climate change, and stimulate economic growth. Accordingly, a research question (RQ) is elaborated: How can experiential learning activities, regarding the CE and SCM, enhance sustainability-related learning outcome growth and relevance in industrial engineering education?

To address the RQ, this article is structured as follows: Section 2 explores the intersection of SCM and CE for academic and practical purposes. This section also introduces the conceptual framework and pedagogical approach designed to immerse students in CE education within the context of SCM. It outlines the fundamental assumptions of the study and provides the necessary conceptual background for the proposed framework and methodology. Section 3 showcases a case study that illustrates an active learning experience focused on CE challenges in small and medium enterprise (SME) supply chains. Section 4 discusses the results, highlighting key findings, limitations, and potential areas for future research. Finally, Section 5 offers the conclusions and contributions of this research, summarising its impact and significance.

2. Background

2.1. Circular Economy, SMEs and Supply Chains

The CE embodies a transitional shift from the conventional extract–produce–dispose linear model to a more sustainable structure focused on reducing, reusing, and recycling [6]. This model aims to minimise waste, decrease resource consumption, and promote regenerative industrial practises. It seeks to change mindsets and rethink existing structures, retaining economic value while benefiting society and the environment [28]. It emphasises using a systemic perspective for closing material, energy, and information loops by designing products for longevity, recovering resources, and reducing waste.

Industrial and systems engineering, which focuses on optimising business processes, improving efficiency, and dealing with potential side effects, is crucial in this transition. It oversees the circular movement of materials, products, and information in forward and reverse supply chain flows [29,30].

Incorporating CE principles into business practises can offer significant benefits, including cost savings, revenue generation, and competitive advantages. However, implementing these practises is challenging due to technological, economic, regulatory, and organisational barriers. There is still work to fully understand the role of operational practises related to the CE in attaining the Sustainable Development Goals (SDGs), particularly SDG #12 Responsible Consumption and Production [31]. In this case, CE practice must consider SDG Target #12.4 "*By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment*" and SDG Target 12.5 "*By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse*" [32].

Regarding SMEs, these face unique challenges when integrating CE principles into their supply chains. Unlike larger companies, SMEs often operate with limited financial resources, lack specialised technical expertise, and have restricted access to broader markets. However, despite these barriers, adopting CE principles and practises offers significant economic, environmental, and social benefits for SMEs (and their communities), which requires practical strategies [33]. SMEs can start by adopting small-scale circular practises in their take, make, distribute, use, and recover operations before expanding to more comprehensive strategies. By rethinking their supply chains, SMEs can reduce costs by reusing materials, refurbishing products, and minimising resource consumption and waste to make their processes and energy consumption more efficient [34]. They can also enhance their brand reputation by offering unique, eco-friendly products and services that differentiate themselves in the marketplace. Furthermore, SMEs can ensure compliance with increasingly demanding environmental regulations by proactively adopting circular practises to avoid potential fines or sanctions. Governments, industry bodies, and larger corporations can also play a critical role by providing support, resources, and incentives for SMEs to transition to a CE.

Figure 1 presents a framework to explore CE practice developments in SME supply chains and their operations. This framework highlights supply chain modelling using the SCOR (Supply Chain Operations Reference) model for managing and evaluating supply chain performance [35]. The SCOR model provides a comprehensive methodology for improving and optimising supply chain operations. It integrates business processes, practises, performance metrics, and people skills into a unified language that helps organisations streamline their supply chain activities.

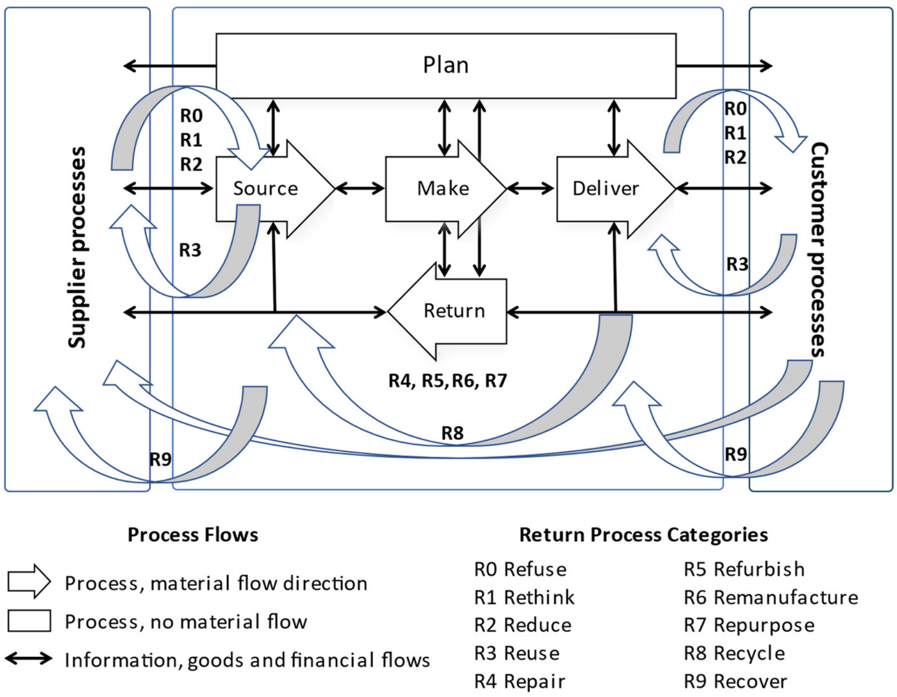

Figure 1. SCOR Supply Chain Mapping for CE in SMEs (authors' elaboration).

The SCOR model facilitates specific supply chain mapping involving business processes using Levels I (i.e., process types) and II (i.e., process categories). The mapping process begins at Level I, where the supply chain process types under study (source, make, deliver, plan, and return) are identified, going from supplier to customer processes. Later, process categories are specified (e.g., return process categories such as refuse, rethink, and reuse) along the supply chain. Consequently, the SCOR model mapping can help describe relevant supply chain processes and solutions—ranging from R1 to R9—within a particular SME for CE improvement.

In higher education, the challenges and opportunities of CE practise adoption in SMEs create a platform for responsible management education. By integrating sustainability, CE principles, and the SDGs into learning experiences, educational institutions can equip learners with the necessary knowledge and skills to drive future change, in line with the Principles of Responsible Management Education (PRME) [36,37]. Accordingly, a suitable pedagogical approach is required to link the real-world SME challenges and opportunities of adopting CE practises to enhance students' learning relevance and learning outcome development in industrial engineering education.

2.2. Experiential Learning

HEI can increase their relevance by including the practical application of CE concepts in experiential learning activities [9,10]. However, integrating CE concepts into higher education activities is still in its early stages and is primarily confined to specific courses or programmes. A particular approach for conceptualising and further exemplifying experiential learning activities is needed for purposeful CE learning activities.

Experiential learning, rooted in constructivist theory, suggests that learners actively construct knowledge through direct experiences [38,39]. This hands-on approach enables students to achieve targeted learning outcomes by engaging with real-world situations and reflecting on their actions and observations. Teaching is not merely delivering information but involves taking students into reflective and practical learning. It builds on their understanding, modifying behaviours and choosing new experiences [40–42]. This learning approach comprises a recurring cycle of concrete experience, reflective observation, abstract conceptualisation, and active experimentation [43,44].

Concrete experience is a novel situation stimulating an active engagement in a task for further action. Reflective observation involves contemplating the triggering situation and recognising discrepancies, gaps or breakdowns in the learner's comprehension and existing knowledge. Abstract conceptualisation is concerned with creating new views and ideas or changing judgements resulting from their reasoning. It also comprises new interpretations and intellectual developments from fresh knowledge creation. Finally, active experimentation consists of learners' conceptual applications and implementations, guiding their actions and behaviours amid the original stimulating situation. This stage covers experience testing, validation, and feedback to conclude and move forward to face new experiences [41]. It is claimed that each stage follows its predecessor in a continuous sequential logical pattern.

Kolb and Fry [42] suggest that learning is an ongoing process of making meaning through personal and situational experiences. In this process, learners perceive, reflect, create, and act within specific circumstances. Engaging in experiential learning is believed to enhance learners' interest, motivation, and engagement by offering various situational selections or pathways [45–47]. Therefore, experiential learning increases learning relevance by making stronger connections between learners' involvement, practises, and applications [48–51]. This perspective advocates assessing students' knowledge, skills, and abilities in contexts that reflect real-world tasks, emphasising self-directed learning and cognitive challenges [52,53].

The experiential learning theory can assist learners in engaging in practical problem-solving, decision-making, and policy-making activities [54,55]. This proposition covers situational observation, problem assessment, solution design, and validation, which requires effective action in contrived scenarios or the real world [56]. This viewpoint is especially beneficial in engineering education, where engaging hands-on activities and realistic simulations are employed to devise technological solutions [57–60]. In contrast, some critiques of experiential learning suggest that it may overlook cultural differences, contextual conditions, and the emotional states of learners and educators [61,62]. Critics also question its consideration of diverse learning modes and types, knowledge acquisition processes, and whether learning occurs in distinct phases. Despite these criticisms, scholars acknowledge the acceptance and widespread usage of experiential learning in educational practice [61,63,64]. While addressing every critique of experiential learning is beyond the scope of this work, these considerations are valuable for identifying the limitations of this work.

2.3. Circular Supply Chains in SMEs for Experiential Learning

The education of circular operations management necessitates pedagogical strategies that foster practical application, reflection, critical thinking, active participation, innovation, creativity, and holistic thinking [11]. Consequently, active pedagogical methods, particularly experiential learning, are well-suited to these educational objectives [8,15,65,66]. According to the Principles for Responsible Management Education (PRME), students should be involved in both the conceptualisation and implementation of learning experiences that support experiential learning aligned with the Sustainable Development Goals (SDGs) [36,37]. Therefore, the primary aim of this study is to design educational activities for circular SCM from the experiential learning perspective. This perspective contributes to SDG Target 4 "*By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development*".

This work considers a recursive experiential learning circle, concerning circular supply chains. The experiential learning cycle is outlined as follows.

A concrete experience might consist of learners perceiving and interacting with supply chains (and their relevant stakeholders) in a real-world situation involving issues, challenges, or problems related to waste generation or the linear economy in organisations. These activities might be accomplished by field visits, talking to guest speakers, simulations, or hands-on activities in immersive experiences.

Reflective observation involves critically evaluating CE scenarios within SCM. This process aims to thoroughly understand key assumptions, identify potential obstacles, and consider possible impacts. Effective pedagogical methods for this stage include group discussions, collective reflections, and self-assessments. These activities enable students to make sense of their experiences, drawing out key insights and lessons learned through SCM and CE models and framework applications. This is the case of using the SCOR [35] and the Ellen MacArthur butterfly model [6] in line with SDG #12 Responsible Consumption and Production for reflecting on the supply chain regarding the biochemical restoration or the maintenance, reuse/redistribution, refurbishment/remanufacturing, and recycling of materials, components, or parts in manufacturing, production, or service processes.

Abstract conceptualisation involves students generating new ideas, establishing connections, and developing innovative solutions for supply chain challenges within the CE. This approach crafts CE strategies tailored to particular supply chain operation scenarios. It involves devising circular engineering solutions, suggesting CE performance measurements, reconfiguring supply chains, or developing circular business structures to achieve zero waste and minimise social and economic impacts.

Active experimentation entails hands-on engagement, prompting students to test and validate CE solutions in realistic scenarios. This can take various forms, such as developing implementation plans, conducting demonstrations, applying practical solutions, giving presentations, participating in debates, engaging in role-plays, or running simulations. The goal is to empower students to critically assess their proposals, gather feedback, and collaboratively arrive at viable solutions for supply chain practises.

Accordingly, this work examines learning experiences rooted in experiential learning to meet educational objectives, address specific disciplinary content, incorporate CE-related challenges, and cultivate targeted learning outcomes. Nonetheless, this necessitates a well-structured instructional design to facilitate their unique developments [67,68].

3. Methodology

The ADDIE model for instructional design was chosen in this work as an effective and efficient alternative to creating learning experiences [69–71]. The ADDIE acronym represents five essential phases of instructional design: analysis, design, development, implementation, and evaluation. Each phase is interconnected, providing a structured approach to developing instructional materials and courses that meet learners' needs and achieve specific learning objectives. Overall, the ADDIE framework helps to define *what to learn*, *how to learn*, and *how to assess learning* [49].

The first phase, analysis, involves identifying the learning problem or challenge, defining the instructional goals and learning outcomes, and understanding learning requirements and target students. The analysis phase aims to understand instructional goals and objectives. In the design phase, the instructional designers create a detailed blueprint for the learning experience. This includes outlining the learning content, choosing appropriate instructional strategies, and designing the content structure.

The development phase is where the instructional resources are created based on the design plan. This involves developing the necessary instructional content, including text, graphics, multimedia, assessments, and other learning resources. The implementation phase includes carrying out the learning experience. This phase includes preparing the learners and instructors, setting up the learning environment and instructional format, providing student support, and distributing the course content.

The final phase, evaluation, assesses the effectiveness of the overall learning experience. This commonly involves assessment methods of student learning outcome progression and achievements, whether the instructional objectives were met, and areas for further improvement.

Consequently, the ADDIE model is incorporated into the research methodology, considering the following steps.

1. Identify the focus of the study based on the RQ by utilising relevant theories and concepts, the overall research objective, and the ADDIE model.
2. Create a pedagogical design and choose a specific learning experience, serving as an exploratory single case study to address the research aim and question. This study adopts a qualitative research methodology based on the case study approach to systematically investigate the intricate details, complexities, and unique characteristics of a specific learning experience. A case study showcases a learning experience instructional design through a thorough examination based on the ADDIE model. A case study was chosen for this work because it is particularly suited to unique circumstances or single occurrences that happen infrequently or for detailing the application of new methods and techniques. Consequently, this method avoids using control groups to derive comparisons, inferences, or generalisations about comparable scenarios, instances, or situations [72–75]. In this work, the ADDIE model guided the creation of a circular supply chain learning experience for an undergraduate industrial and systems engineering course at Tecnológico de Monterrey in Mexico City, engaging a group of SMEs from various sectors. The ADDIE model for the learning experience is detailed in Table 1.
3. Gather data and formulate responses to the RQ. This process employs a mixed-methods approach for data gathering and analysis. Primary data were collected from reports by students and instructors regarding the ADDIE instructional design and learning experiences, providing essential context. Regarding students, data were collected using an opinion survey known as "encuesta de opinión de alumnos" (ECOA) in Spanish, regarding the course experience. The ECOA survey is a centrally and independently managed online instrument applied by the university's registry for one week (during week fourteen of the module) before the final examination. All students received a survey weblink in their university email, which they anonymously and voluntarily accessed. This type of data collection can be regarded as self-selection, non-probabilistic sampling [76–78]. The survey consists of eight 1-to−10-scale questions and one additional question to provide feedback commentary. The survey results were disclosed to instructors after completing and reporting the module evaluations. Regarding instructors (one of the authors), they provided verbal and written reports on the specific components for each ADDIE stage. Additionally, secondary data were gathered from institutional and academic course documents, including the

syllabus, assignment briefs, and course materials. Exam results were also collected to evaluate student learning outcome achievements, including formative and summative assessments. Furthermore, student feedback was obtained from the course and learning experience opinion surveys. The collected data underwent analysis through descriptive statistics, encompassing measures such as the mean, standard deviation, mode, and interquartile range (IQR). This work only used information concerning the module description, activities, and learning attainments. Personal data were not deemed necessary for instructional design purposes. Hence, no students' personal information was collected or used in this work, as this is legally protected and for which access was not requested.

4. Evaluate and discuss results with the underlying theories and adjust or eliminate any statements and claims as necessary. This may also prompt the need for additional actions, such as implementing enhancements, changes, or adaptations for future learning experience developments and implementations.
5. Present the findings and determine subsequent actions based on the results. This phase involves the research outcomes and contributions, highlighting any limitations encountered and outlining potential directions for future work. It may also necessitate revisiting step 2 in a research refinement sequence. If the propositions, claims, or statements remain unchanged across subsequent learning experiences, the results can be extrapolated and utilised to enhance future projects or cases.

Table 1. Learning experience design using the ADDIE model-based framework.

Stage	Description
Analysis	1. Module/course selection: Select a course or module that integrates circular SCM concepts, tailored for industrial and systems engineering students at the higher education level. 2. Problem situation/challenge definition: Identify realistic challenges demonstrating how SME supply chain operations affect sustainability, providing a practical context for learning. 3. Intended learning objectives: Set specific learning objectives that focus on the sustainability impacts of supply chains within SMEs, ensuring students understand the relevance and importance of these issues. 4. Learning outcomes and competencies: Outline the expected student outcomes to create CE solutions for SCM in SMEs. 5. Format: Choose the most suitable instructional format for the learning experience, whether present, online, blended, or hybrid. 6. Target learners: Set the target for students concerning their study progress, discipline, and programme.
Design	7. Knowledge identification: Recognise key themes within SCM that relate specifically to the CE and SMEs in line with SDG #4 Responsible Consumption and Production. 8. Teaching and learning approach: Select the primary pedagogical method—experiential learning—, emphasising reflective and hands-on real-world engagement. 9. Experiential learning activities: Develop and outline experiential learning activities, ensuring a thoughtful hands-on educational experience.
Development	10. Course materials preparation: Assemble all necessary module learning resources and materials to support the objectives and learning activities.
Implementation	11. Implementing the course/module: Conduct the learning experience by delivering lectures, facilitating seminars, and engaging in various interactions. Collect and evaluate students' learning outcome results.
Evaluation	12. Evaluation of learning outcomes and experiences: Develop detailed coursework rubrics and evaluation tools for students. Administer surveys to gather student feedback on the learning experience and the course content.

In summary, the methodology outlined encompasses a comprehensive research design, a structured model for crafting effective learning experiences, and a detailed case study. This approach provides a platform for grasping the intricacies of experiential learning while generating valuable insights for teaching practice. Integrating the ADDIE model and the experiential learning cycle into an instructional design framework for learning outcome development concerning CE solutions for SCM education represents the main proposition of this work in line with its research aim and question. The subsequent section will examine the results of this methodology, showcasing its implementation in a learning experience focused on circular supply chains in SMEs. This exploration sheds light on the practical lessons from integrating theoretical concepts into actionable learning scenarios.

4. Results

This section presents a case study of a circular supply chain learning experience to illustrate the concepts discussed in this work. The case is organised into three subsections. The first subsection introduces the learning experience, providing a rationale for studying circular supply chains within SMEs in the context of an undergraduate industrial and systems engineering course. The second subsection outlines the learning experience design, following the ADDIE model structured framework. Finally, the third subsection details the implementation and evaluates student learning outcome achievements and feedback.

4.1. The Learning Experience

IN3037 Design and Improvement of Logistic Systems is a seven-semester module (running for sixteen weeks) of the Industrial and Systems Engineering programme at Tecnológico de Monterrey in Mexico. It involves analysing and designing supply chains using optimisation methods and considering different stakeholder perspectives. However, the course lacks a link to sustainable development requirements and their implications for supply chains. Thus, IN3037 was selected to develop CE learning outcomes concerning SMEs.

Previously, the teaching team designed and implemented learning experiences involving SMEs as academic partners with positive results. Hence, involving SMEs again gave students real-world challenges in a new purposeful scenario.

Accordingly, fifty-six students of two cohorts from two campuses in the Mexico City metropolitan area enrolled in IN3037 to carry out a learning experience on circular supply chains in SMEs to reduce/eliminate waste, enhance environmental/social impact, and increase operational efficiency. Students were organised into eleven groups to study one SME partner each. A total of two instructors were involved in teaching, mentoring, and coaching students in their learning activities.

4.2. The Learning Experience Instructional Design According to the ADDIE Model

4.2.1. Analysis

- The course selection: IN3037 Design and Improvement of Logistics Systems is an intermediate-level offering that equips students with advanced concepts in the analysis and design of logistics systems. It plays a critical role in the ABET accreditation to develop key engineering student outcomes for undergraduate programmes [79]. Additionally, this course embodies a transdisciplinary competence aligned with the university's educational model, aiming to develop committed, sustainable, and supportive solutions to social issues. These solutions are formulated to promote democracy and the common good on both regional and national levels. The course draws on theories of citizenship, social responsibility, and social sciences, as well as research methodologies in social development, all of which are integral to addressing the targeted problems.
- Problem situation/challenge definition: This points to sustainability challenges in SME supply chains following the global COVID-19 pandemic concerning the CE. SMEs have been disproportionately impacted in their operations by the pandemic at this time, highlighting their vulnerability during such sanitary crises. In the case of Mexico, SMEs are often referred to as the backbone of the Mexican economy, contributing significantly to its gross domestic product (GDP)—approximately 52%—and generating 70% of its formal employment. However, during the pandemic, the Latin

American Association of Small and Medium Enterprises (ALAMPYME) reported in March 2020 that approximately 4.5 million SMEs in the region were navigating through uncertainty and had incurred losses nearing 30,000 million Mexican pesos [80]. The ALAMPYME also highlighted that 77% of SMEs were at risk of ceasing operations, 25% had to lay off employees, 47% were struggling with customers' receivables, and 87% were facing declines in sales, customers, and new projects. The limited resources can hinder Mexican SMEs' integration of sustainable practises into their supply chains. Consequently, challenging learning experiences can help SMEs adopt circular practises, benefiting students and businesses. Nevertheless, sustainability-related practises require a shift in mindset from short-term profitability to long-term value delivery, encompassing environmental and social dimensions. This shift can be challenging in SMEs where the culture may be deeply rooted in traditional businesses. Therefore, a learning experience where industrial engineering students addressed CE issues in SME's supply chains was relevant and appropriate within the IN3037 Design and Improvement of Logistics Systems course.

- Learning objectives: The IN3037 Design and Improvement of Logistic Systems course aims to teach students to model, design and improve logistic systems, and determine relevant operations costs and appropriate configurations to achieve supply chain integration. The learning content comprises mathematical and conceptual modelling, simulation techniques and technologies, and planning models. Moreover, the learning objective extends to include CE practises within the supply chain design to develop circular supply chain solutions for Mexican SMEs.
- Learning outcomes: This course considers the definition of the Accreditation Board for Engineering and Technology (ABET) of the engineering student learning outcome (K), and the university's ethical commitment and citizenship student outcomes as follows:
    - a. Learning outcome (K) engineering practice is defined as the ability to utilise the techniques, skills, and contemporary engineering tools essential for professional engineering practice [79].
    - b. Citizenship commitment refers to the capacity to develop dedicated, enduring, and beneficial solutions to societal challenges and requirements. This is achieved through approaches that enhance democratic values and promote the community's well-being [81].
- Format: This immersive learning experience mandated that students engage directly with SME supply chains through observation and data collection. Course materials and lectures were delivered on-site across two campus locations. Instructors selected eleven SMEs for the project, each assigned to a student team comprising four to five members. All participating SMEs were situated in the Mexico City metropolitan area.
- Target learners: Fifty-six seven-semester industrial and systems engineering students of two cohorts on two campuses.

4.2.2. Design

- Knowledge acquisition:
    - a. Fundamental SCM and CE concepts to understand the need for circular supply chains;
    - b. Advanced mathematical modelling of supply chain networks for process optimisation;
    - c. SCOR model processes and metrics to initially diagnose the current state of the supply chain ("as is") and subsequently develop a proposed future state design ("to be") incorporating CE solutions [59]. The activities were as follows:
        - i. A preliminary formulation of the situation using the SCOR [46] model to map the current SME's supply chain configuration (as is) and collect data (using a questionnaire) on the existing waste generation at each company;

ii. The elaboration and agreement of a project charter (with the SME executives) showing milestones, deliverables and roles;
iii. Quantification of SCOR model metrics and generated waste;
iv. The elaboration and validation of CE proposals for SME's supply chain and/or business model redesign to reduce/eliminate waste.

- Teaching and learning approach: Experiential learning.
- Experiential learning activities: Students engage in activities following the principles of the experiential learning cycle. Table 2 summarises the activities concerning the CE and SCOR model. These activities involved disciplinary studies linked to SCM and customer engagement content. These also involved addressing problem situations through synchronous and asynchronous individual and collaborative work among students.

Table 2. Experiential learning activities.

Experiential Learning	Activity Description	Method Steps
Concrete experience	Collect quantitative/qualitative data regarding SME supply chain processes and key performance indicators (KPIs) using the SCOR model; Collect and classify quantitative/qualitative data about SME waste generation and management practises in line with the Ellen MacArthur butterfly model and SDG #12 Responsible Consumption and Production.	Formulation of the situation
Reflective observation	Examine key supply chain processes affecting waste generation; Map supply chain processes at the configuration level. Quantify level 1 and 2 SCOR metrics; Recognise an issue or problem in supply chain processes regarding waste generation; Link the issue or problem to CE concepts and tools.	Diagnose
Abstract conceptualisation	Identify waste elimination, reduction, or minimisation strate gies; Identify changes to the supply chain configuration; Elaborate supply chain improvement proposals.	Elaboration of proposals
Active experimentation	Evaluate/validate CE solution proposals considering waste quantification using SCOR KPIs.	Evaluation

4.2.3. Development

- Educational resources: This course necessitated a range of educational resources, including the following:
    a. A comprehensive syllabus detailing the learning objectives, student outcomes, teaching content, learning activities, assessment methods, materials, reading list, and bibliography.
    b. The course utilised Canvas©, a web-based learning platform, to support distant mentoring and teamwork, ensuring seamless communication and interaction among students and instructors.
    c. SCM and CE slide packs and reading lists on the virtual learning platform.

4.2.4. Implementation

- Course module execution: The module was conducted simultaneously on two campuses, featuring regular classroom lectures. The learning experience spanned a sixteen-week semester, with the course structure including three-hour teaching sessions and three hours of on-demand mentoring each week. Additionally, students were expected to engage in three hours of asynchronous collaborative work weekly. Accordingly, four teaching sessions dedicated to the learning experience covered the following:

a. An introduction to the study scenario outlining the justification, objectives, assessment criteria, and desired learning outcomes;
b. An exploration of the SME situations focusing on how supply chain processes contribute to waste generation, concluding with the stage of concrete experience;
c. A presentation and discussion of significant works on the CE and SCM that address waste generation in SMEs, aligning with the reflective observation stage;
d. An exploration of alternative solutions to the current challenges using CE and SCM principles, methodologies, and techniques, corresponding to the abstract conceptualisation stage;
e. A presentation and discussion of students' proposals, examining their implications, limitations, and potential future work, reflecting the active experimentation stage.

- Student learning results: Table 3 summarises students' CE-proposed solutions for the SMEs under study. The proposed solutions were mapped according to the SCOR process types and categories (return, source, make and deliver). Students initially mapped the supply chain configuration at the present state (not included in this manuscript) and later proposed changes in a future state configuration as summarised in Table 3. These changes included adding or changing suppliers' practises, return processes, and new production/delivery processes. Proposals show proposed changes according to the existing literature in CE, ranging from packaging reduction or elimination to material return and recycling.

Table 3. Students' CE-proposed solutions for SMEs' supply chains.

	SCOR Processes					
SMEs	**Return Process with Suppliers**	**Source**	**Make**	**Deliver**	**Return Process with Clients**	**CE Strategies (9Rs)**
SME 1: Toy retailing		Improvement of forecast accuracy to reduce inventories. Usage of in-house transport		Bicycle deliveries for local online sales. Packaging material recycling	Return process of carton board packaging materials	Reuse (R3) and recycling (R8) of packaging materials
SME 2: Fuel distribution and sale			Paper waste reduction and recycling from administrative support processes through digital solutions	Vehicle tyre recycling in fuel transportation		Reducing (R2) of paper waste. Recycling (R8) of paper Recycling (R8) of tyres
SME 3: Bakery			Elaboration of compost from organic waste such as fruit peel and eggshell	Introduction of reusable and biodegradable packages and cutlery		Recycling (R8) and reuse (R3) of production materials and packages
SME 4: Coffee shop	Packaging material reuse			Packaging material replacement in customer deliveries		Reuse (R3) of packaging materials Reducing (R2) of packaging waste
SME 5: Home decoration retail		Change in product design to reduce material waste		Reuse of ornamental plant containers to replace plants at the end of their life		Reducing (R2) of production waste through product design Reuse (R8) of containers

Table 3. *Cont.*

	SCOR Processes					
SMEs	**Return Process with Suppliers**	**Source**	**Make**	**Deliver**	**Return Process with Clients**	**CE Strategies (9Rs)**
SME 6: Tableware retail	Packaging material reuse					Reducing (R2) of packaging waste Reuse (R3) of packaging materials
SME 7: Beverage syrups production and retail				Replacement of cardboard using reusable plastic boxes in a supply chain return process configuration		Reducing (R2) of packaging waste Reuse (R3) of packaging materials
SME 8: Ice-cream shop		Local supplier utilisation to reduce transport time and emissions	Compost elaboration from organic waste generated in cream production		Waste reduction in packaging and cutlery switching to biodegradable materials and promoting customers' container reuse	Reducing (R2) of ice-cream production transportation time Reducing (R2) of packaging waste Reuse (R3) of packaging materials Repurposing (R7) of organic waste onto compost
SME 9: Scaffolding supply		Special paint usage in scaffoldings after customers' return	Welding reduction in scaffold joints through mechanical clamp use. Production material recycling in new products and spare parts	Scaffold and recyclable plastic cover reduction for tyres and joints		Reducing (R2) of packaging waste Reuse (R3) of packaging materials Recycling (R8) and repurposing (R7) of production materials
SME 10: Sports product retail	Packaging material, cardboard, and pallet use reduction					Reducing (R2) of packaging waste. Reuse (R3) of packaging materials
SME 11: Plastic bottle manufacturing		Plastic material reduction in bottle redesign				Reducing (R2) of material through changes in product design

4.2.5. Evaluation

- Learning outcomes and experience evaluation: Three distinct categories of evaluations and assessments. First, summative and formative evaluations were included to assess students' learning outcome achievements. Second, an assessment was conducted to evaluate students' commitment to citizenship. Last, students provided feedback through an institutional survey—regarding the course and learning experience. The specific evaluation components covered the following:
    - a. Two partial and final exams, which serve as summative assessments;
    - b. Two project partial reports, used for formative evaluations;
    - c. A comprehensive final project report as a summative evaluation.
- Table 4 presents the outcomes of the exams and project reports for a cohort of fifty-nine students. Table 5 details the results related to student learning outcomes in

engineering practice (K) and their commitment to citizenship. Table 6 showcases the findings from the institutional student opinion survey ECOA. The ECOA results summarise descriptive statistics derived from student responses collected by the academic administration. Collectively, Tables 4–6 include descriptive statistics that illustrate the data distribution, encompassing measures of central tendency.

Table 4. Student learning evaluations.

Evaluation	First Partial Exam	Second Partial Exam	Final Exam	First Partial Report	Second Partial Report	Final Project	Final Score/ Grade
Mean (0–100 scale)	90	93.95	89.96	97.13	98.53	98.8	90.34
Standard Deviation	7.20	3.18	15.17	3.95	1.78	2.4	1.32

Table 5. Learning outcome assessment.

Student Learning Outcome	Engineering Practice (K)	Citizenship Commitment (1 Below, 2 Meets, 3 Exceeds Expectations) Scale
Median	3	3
Min	2	2
Max	3	3
Q1	2.5	2
Q3	3	3
Interquartile Range (IQR)	0.5	1
Achievement level 2 or above	100%	100%
Achievement level 3	72.72%	63.60%

Table 6. Student Opinion Survey (ECOA) results.

Student Opinion Survey # of Answers from Students (49 Out of 56)	1. MET	2. APP	3. TUT	4. EVA	5. CHA	6. SUP	7. PRO	8. REC	9. COM (Student Comments)
Mean (0–10 scale)	9.25	9.5	9.56	9.55	9.41	9.52	9.76	9.38	100% of comments highlight satisfaction, clarity of explanations, and instructors' knowledge proficiency.
Standard Deviation	0.91	0.91	0.67	0.61	0.93	0.81	0.68	0.85	

The results indicate that the students attained a passing rate of 90.34% on their evaluations. Additionally, every student met the minimum acceptance criteria in engineering practice (K) and their commitment to citizenship and social transformation. Results from the ECOA survey further demonstrate that all metrics surpassed the established goals, with scores exceeding 9.0 on a scale of 0 to 10.

Table 5 notation is as follows.

- MET—Teaching and learning methodology (0 = Very poor and 10 = Exceptional);
- APP—Conceptual comprehension through practical applications (0 = Very poor and 10 = Exceptional);
- TUT—Tutoring (0 = Very poor and 10 = Exceptional);
- EVA—Evaluation and feedback (0 = Very poor and 10 = Exceptional);
- CHA—Intellectual challenge (0 = Very poor and 10 = Exceptional);
- SUP—Instruction support, assistance, and dedication (0 = Very poor and 10 = Exceptional);
- EXP—Instructor expertise (of the instructor) (0 = Definitively no and
- 10 = Definitively yes);
- REC—Course recommendation (0 = Definitively no and 10 = Definitively yes);

- COM—Student comments.

In summary, the learning experience outcomes reflect satisfactory passing rates, successful student assessments, and favourable feedback from the student opinion survey. All student comments were overwhelmingly favourable.

5. Discussion

5.1. Findings

This study examined the results of incorporating Kolb's experiential learning into a module centred on circular supply chains. By employing this approach, the research outlines the pedagogical design, learning activities, course outcomes, and student feedback, all aligned with the defined course objectives. The findings shed light on the strengths, weaknesses, opportunities, and challenges of integrating CE concepts into SCM learning activities. A summary of these insights is presented in Table 7.

Table 7. Strengths, weaknesses, opportunities and challenges.

Category	Details
Strengths	a. Integrating experiential learning into the ADDIE model as the guiding pedagogical approach.
	b. Relationship with SMEs as educational partners providing operations and process information.
	c. Faculty's pedagogical experience in active learning.
	d. Selection of a relatable study topic for company operations and students' intended learning in SCM.
	e. High student participation and interest in real-world CE business activities.
	f. Students conducting independent research and situated experiential learning.
	g. Interdisciplinary topic integration (CE, SCOR model, and SCM) to address real-world challenges.
	h. CE-related learning in alignment with SDG #4 Quality Education and SDG #12 Responsible Consumption and Production.
Weaknesses	a. Limited study time to address CE topics—just a semester-long academic period.
	b. Extra resource allocation to execute the learning experience.
	c. No precise impact evaluation of student learning outcomes, knowledge, and skills attainment.
	d. No follow-up of CE solutions' implementations.
Opportunities	a. Exploring additional sustainability topics like gas emissions and energy consumption.
	b. Expanding the study of CE-related topics to other engineering courses.
	c. Transferring this approach and methodology to other instructors.
	d. Establishing knowledge exchange partnerships with other local companies.
	e. Further exploring other disciplinary and interpersonal skills and learning outcomes.
Challenges	a. SME engagement and coordination.
	b. Reducing extra planning time and effort beyond regular workload allocation.
	c. Attaining challenge-expected results in line with intended learning objectives.
	d. Maintaining a safe and inclusive learning environment for students in real-world settings.

The learning experience leveraged experiential learning, fostering hands-on, contextualised, and reflective learning through customised CE solutions in SME supply chains. It benefited from strong partnerships with SME partners, faculty experience, and a carefully chosen study topic relevant to company operations and learning objectives. High student engagement and interdisciplinary topic integration enhanced students' learning and marks. Students grew relevant sustainability-related learning outcomes through their active problem-solving engagement in SME real-world environments.

Weaknesses include limited formal time for sustainability topics and requiring extra effort from faculty for the learning experience planning and execution. The project lacks precise assessments of the student learning outcomes, linking CE learning activities to student achievements. Additionally, a limited budget restricted the scope of student activities.

There is significant potential to explore additional sustainability topics and extend the study to other engineering courses. Training other teachers in sustainability education and establishing ongoing collaborations with local companies can further enrich the research initiative. Additionally, there are opportunities to strengthen the development of students' personal and technical skills, like teamwork, problem analysis, and policy-making.

The primary challenges include engaging and coordinating with SMEs, which can be complex and time-consuming. Additionally, reducing extra planning time and effort beyond regular workload allocations poses a significant challenge for faculty. Achieving results that align with the intended learning objectives requires careful planning and execution, ensuring that the educational goals are met. Moreover, maintaining a safe and inclusive learning environment for students in real-world settings is crucial, necessitating thorough preparation and ongoing attention to student well-being and inclusivity.

Furthermore, the learning experience had positive course passing rates, project marks, and student opinions. Students achieved higher mean marks on the project concerning the final exam, with a minor standard deviation and IQR. These findings align with preceding research on experiential learning [9,51]. Course marks and survey results indicate an effective student attainment of learning objectives.

According to the student opinion survey, the learning experience was highly valued, with a median score of 9.38 for course recommendation (REC), 9.41 for intellectual challenge (CHA), and 9.5 for concept comprehension in practice (APP). It is worth mentioning other positive results concerning the teaching methodology (MET), tutoring (TUT), and instructor support, assistance, and dedication (SUP), Additionally, 100% of student comments reflected satisfaction, clarity of explanations, and instructors' knowledge and support. These high scores demonstrate students' excellent appreciation for the course and the learning experience. Finally, regarding engineering practice (K) and citizenship commitment, assessment results show a 100% achievement above the level 2 (meet expectations) target whereas 72.72% and 63.6%, respectively, attained level 3 (exceed expectations).

Concerning the CE-related student work, solutions demonstrated students' capability to address CE questions in SME processes and operations. Students' marks on the final project achieved a 98.8 average result (0–100 scale), showing high acceptance from the SME staff and tutors. These results demonstrate the achievement of learning objectives and the development of positive learning outcomes in this learning experience.

In conclusion, students effectively tackled solid waste issues through experiential learning. This experience enabled them to connect real-world challenges related to the CE with industrial engineering concepts and practical problem-solving methods. As a result, they participated in experiential learning that enhanced their personal growth while benefiting their educational partners. This learning journey illustrated how undergraduate students can extend their learning beyond the classroom, broadening the scope of application cases in SCM education.

This research advances the field of education by enriching the development of experiential learning cases in higher education, specifically by integrating CE principles into SCM programmes. This innovative pedagogical design yielded positive outcomes that transcended traditional disciplinary boundaries.

Overall, the results underscore the efficacy of experiential learning actively involving students. This study offers valuable illustrations for educators that cultivate students' commitment to sustainability and progress towards a CE in SCM. The ADDIE model (integrated with the experiential learning cycle) served as the foundational framework for this pedagogical development, representing the main contribution of this work.

Finally, this work's development and results provide links to the experiential learning literature in sustainability education for learning and teaching practice as follows:

- Experiential learning as a catalyst for sustainability awareness and global change [82]. There is a connection between learners and the environment (i.e., SME's supply chains) through immersive learning experiences that foster a sense of responsibility towards sustainability (i.e., solid waste reduction). It also underscores skills development (i.e., citizenship commitment and engineering practice learning outcomes) through incorporating experiential learning into curricula (i.e., IN3037 Design and Improvement of Logistic Systems module).
- Experiential learning for problem-solving [83]. Students learn to identify and address real-world sustainability problems, applying existing knowledge to develop alternative solutions.
- Experiential learning through participatory community engagement [84–86]. A participatory and hands-on experiential learning approach helps empower communities and SMEs, while also benefiting students' academic, professional, and personal growth, including citizenship commitment and engineering practice outcomes.
- Experiential learning for CE education [9]. An experiential learning approach can help integrate real-world circular economy challenges (i.e., waste reduction and elimination in supply chains) into learning activities, providing conceptual understanding, critical thinking, active engagement, and practical implementation (as indicated in Table 5 strengths).

5.2. Limitations

This work has several limitations regarding the pedagogical approach. Experiential learning can be ambitious, requiring students to tackle complex, real-world problems. This can lead to broad or unfocused projects, making it difficult for students to achieve concrete learning outcomes. This definition turns difficult especially when reaching agreements with SME learning partners. Therefore, this demands clear, realistic, and manageable scopes for challenges according to course timelines. Each SME required specific scope definitions and agreements, significantly increasing the planning and follow-up efforts.

In addition, tutors must be adequately prepared or trained to facilitate experiential learning effectively. Transitioning from traditional teaching methods to a facilitator role requires a different skill set and mindset. However, the tutors in this case were appropriately trained, underscoring the need to secure this aspect in future developments.

Moreover, experiential learning can require significant resources and workload, including time and access to real-world environments. This can be a barrier for HEI with limited funding or for large-scale classes. Focusing on small-scale challenges might be a feasible option. In this case, the effort required a teaching team (two instructors) to support and guide students during the challenge. However, an extra instructor became necessary to alleviate student support demand.

It is worth mentioning that this work offers a pedagogical alternative for instructional design amid sustainability education. Therefore, the focus is on identifying what to learn, how to learn, and how to assess learning based on the ADDIE model and Kolb's experiential learning cycle. Accordingly, this work does not address other aspects of teaching and learning, such as external variables that affect the learning process, learning environments and spaces, student motivation and interest, learners' readiness, learning styles, and learning effectiveness. Moreover, this work's future implementation might be hindered or limited by particular academic policies and regulations, or pedagogical preferences regarding students' involvement in practical real-world activities.

Another limitation is the methodology, as this research is based on a single learning experience case study. As this work explores learning experiences in a social context, the evaluation must adhere to transferability, reliability, and validity criteria [87–89]. Transferability, as generalisability, indicates in this work that findings might not apply to other educational contexts due to differences in data and contextual conditions, leading to varying results and interpretations. Further implementations are required for validation or falsification. Therefore, no claims are made about this work results' generalisation to other instances or situations as further implementations are required for validation or falsification. Reliability was ensured by providing a consistent, step-by-step methodology for data collection, analysis, and reporting across different learning experiences. Validity was addressed by discussing the accuracy of results in light of the experiential learning theory to identify matches or deviations. These criteria suggest implications and further research and provide valuable insights for similar future initiatives.

Additionally, student opinion surveys or student skill assessments may be influenced by subjective viewpoints. This difficulty demands clear and consistent rubrics and criteria, incorporating qualitative and quantitative measures of student achievements. The student survey results were cross-referenced with course feedback, and both consistently showed high scores.

Finally, there were limitations related to data collection and the assessment and evaluation tools designed for this learning experience. This work only focused on gathering data on final learning results, learning outcome development, and module opinion. Future efforts should focus on longitudinal data collection, defining additional metrics, and creating specific instruments concerning learning effectiveness and achievements, learning motivation and interest, student satisfaction and engagement, and course recommendations.

5.3. Future Work

Further developments in circular supply chain challenges are needed to enhance sustainability education. Though experiential learning is well-known, it requires additional implementations and exemplifications to produce new insights and recommendations. Future work should also focus on developing new instances across different businesses, industries, and operational contexts. This is the case with food and fast fashion chains, which heavily generate waste and harm the environment.

Additionally, addressing the limitations of the research methodology is crucial. This includes improving longitudinal and long-term data collection and analysis and research methods to explore new study variables, especially student engagement, motivation, and interest, student attainments, learning effectiveness and skills development in additional case studies, and learning experience instances. Further exploration is required to understand similarities or variations on how course design influences specific learning outcomes, ensuring they align with the intended objectives.

Moreover, future research should explore, for instance, the dynamic interplay between Kolb's learning styles and the experiential learning cycle by investigating how different instructional designs can be tailored to optimise learning outcomes for each style. By closely monitoring and analysing students' performance and engagement across these tailored activities, instructors can gain deeper insights into how learning styles influence learning efficacy [90]. In this case, learning styles mapped on abstractness versus concreteness and action versus reflection activities can be explored as a complementary research initiative.

An additional alternative for future work refers to the link of experiential learning to student interest, motivation, and engagement [45]. In this case, the learning relevance of sustainability-related issues and the CE can help explore how student perceptions change with studying these topics, influencing their attitudes and participation.

Although this study emphasises experiential learning, future efforts could explore other active approaches for circular supply chain education, such as project-based or problem-based learning. Nevertheless, these pedagogies involve different assumptions and understandings of student learning and real-world engagement. Therefore, other types of learning experiences might be created. Finally, exploring additional sustainability topics in supply chains could provide valuable insights into developing learners' sustainability awareness. Sustainability challenges might involve food security, gas emissions, energy consumption, and social inclusion, creating vast possibilities to enrich learning experiences.

6. Conclusions

The CE offers a highly relevant opportunity to create innovative practical learning experiences within SCM education, effectively engaging students in achieving their disciplinary and sustainability-related intended learning outcomes. Educators can create impactful study scenarios by connecting real-world sustainability issues with pressing business operational challenges. CE topics can seamlessly integrate into key SCM areas like product design, inventory management, production, transportation, and warehousing.

This work's primary contribution consists of an instructional design framework based on the ADDIE model and Kolb's experiential learning cycle. This study outlines activities corresponding to each phase of Kolb's experiential learning cycle. It begins by offering learners tangible experiences related to solid waste generation in SMEs' supply chain operations. Next, it facilitates reflective observation to grasp the waste's root causes. Later, abstract conceptualisation engages learners to develop CE-based solutions, followed by active experimentation where they present, test, and validate their proposals. The ADDIE model allowed for incorporating experiential learning activities into an actionable pedagogical design structure. Thus, this approach provides an alternative answer to the initial RQ by implementing an active learning strategy for instructional design focused on developing sustainability-related learning outcomes for the circular economy in supply chain management education. Accordingly, this work offers educators—and illustrates—an option to enrich their pedagogical design toolbox for creating novel experiential learning cases.

A case study involving eleven SMEs' supply chains was used to demonstrate these ideas, offering valuable insights for teaching practises. The main focus was to develop highly relevant applicability through problem-solving across various business industries. The CE, the SCOR model, and the SCM concepts, in line with SDG #4 and #12, offered a pertinent and novel approach in this work.

This work highlights the integration of experiential learning into sustainability education, emphasising its importance for fostering sustainability awareness and problem-solving skills. It connects learners with real-world environments, like SME supply chains, enhancing their sense of responsibility and practical skills. This approach also empowers communities and businesses through participatory engagement, benefiting students' academic and professional growth. By incorporating real-world circular economy challenges into curricula, experiential learning promotes critical thinking, active engagement, and the practical implementation of sustainability practises.

However, research limitations must be considered regarding the ADDIE model and experiential learning cycle, complex real-world problem-solving difficulties in learning experiences, their resource-demanding nature, and this work's restricted transferability and validity resulting from the case study methodological approach. Moreover, future research is also essential to fully assess and evaluate the effectiveness of these learning experiences and their contribution to enriching students' learning attainments. Additional case studies and learning experience instances for different learning styles across diverse industries and contexts should help test and refine the approaches and propositions in this research. Addressing these limitations and future work is crucial for maximising the educational benefits and practical application of the experiential learning approach in engineering education.

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