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SPECIAL FOCUS PAPER

Blended Learning Approaches for Engineering Students: Embedding the Triple Bottom Line in Supply Chain Education

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ABSTRACT

Graduates from the engineering field starting their careers in supply chain and logistics have begun to be balanced on cost efficiency, environmental sustainability, and social responsibility from the beginning of their careers, all considered the TBL (triple bottom line). This paper proposes a blended learning framework for TBL integration into the supply chain for undergraduate and postgraduate engineering students. The framework incorporates self-paced micro-learning, collaborative problem-solving seminars, work-integrated learning, and reflection to develop systems thinking, ethics, and quantitative decision-making. Practical advice on how to implement the blended approach is provided through a sample module, assessment rubrics, and program evaluation strategies. With relativity to other faculty, this approach is designed for single-course implementation all the way to program-wide flexibility. This framework builds on the gap between engineering education and blended sustainability frameworks, preparing graduates to manage a global supply chain ethically and sustainably.

KEYWORDS

blended learning, triple bottom line (TBL), supply chain education, sustainability, engineering pedagogy, project-based learning

1 INTRODUCTION

Revised engineering education frameworks must include supply chain management due to the intricate nature of global challenges and the importance of training graduates for a personally sustainable future [1]. The integration of social, environmental, and economic value creation within supply chains informs one of the primary educational philosophies: the triple bottom line (TBL) model [2]. Blended learning, as one example of the holistic approach, is another educational value [2].

Adapting engineering education to this philosophy is fundamental to training engineers to aid the UN's Sustainable Development Goals [2]. This is the case since

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the educational system can foster the 'sustainability mindset' necessary, and this is accomplished through interdisciplinarity [2]. By fostering collaboration and reflection, the approach will contribute to the development of system thinking, ethical reasoning, and operational understanding, especially as it relates to addressing the complexities of global sustainable development [3].

This meets the need of the labor market by preparing graduates with social, environmental and problem-solving competencies and innovative "sustainable" problem-solving [3]. Engaging students with critical reflection on the design of sustainability facilitates the development of action competencies, an essential attribute for engineers [2].

Although this presents an innovative instructional design, few programs incorporate sustainability, the triple bottom line (TBL), and blended learning strategies within the supply chain curriculum. Most graduates today emerge from fragmented courses, with no integrated approaches, failing to reconcile the challenges of contemporary supply chains. This study attempts to respond to this need by suggesting a blended learning approach to the supply chain courses for engineering students, integrating triple bottom line.

2 MATERIALS AND METHODS

2.1 Blended learning in engineering education

Blended learning combines in-person teaching with online activities. Most engineering education nowadays employs blended learning [2]. It utilizes the benefits of both classroom interactions and the flexibility of online teaching and learning. The "click-and-brick" model, adopted in the post-pandemic era, has allowed even greater flexibility and personalization of learning [2].

Blended learning makes lifelong learning possible, such that it allows engineers to reskill and upskill within their careers and without many hustles [2]. The inclusion of MOOCs and OERs makes learning resources available for peer-to-peer learning [3]. In addition, the blended system facilitates feedback, whether it is formally from instructor elaborations or from informal support [2].

2.2 Triple bottom line in supply chain and education

In order to maximize sustainable business practices, the environmental, societal, and economic spheres can no longer be within the confines of an organization's profit; larger societal harms present ethical issues, for example, involving the social question [4]. For a globalized economy, the impacts of sustainability need to be wider than the business angle [4]. Elkington's TBL model, introduced in 1997, expands the social and ethical dimensions of business decisions to foster win-win relationships in the supply chains.

The social and environmental aspects need to be fulfilled together with efficiency and profitability. Distrust in external networks negatively impacts organizational performance [5]. Inclusion of the circular economy, social equity, sustainable development, and social cohesion deepens the responsibility of communities as sustainability stewards [5]. Growing regulatory and consumer pressure also increases the supply of sustainable offerings.

Therefore, this has moved from direct supply chain model to a stakeholder middle model that is key to providing united market sustainability, and at the same time applied in all aspect of sourcing, as well as down to life management [5].

2.3 Pedagogical models for sustainability education

The increasing necessity to overcome global challenges such as increasing climate change and resource depletion justifies the need to strengthen the capacity of higher education institutions to facilitate the development of such professionals [6]. Climate change and resource depletion cannot be addressed through the use of archaic transmissive approaches to education, and therefore they require the evolution of transformative participative approaches that encourage cooperation, critical reflection, and questioning [6].

As for the sustainability education, the PBL framework structures the learning around analyzing 'wicked' problems, pays attention to collaborative work, and cultivates the deep and systems thinking and the analytical and problem-solving skills fundamental for sustainable development. Embedding the Sustainable Development Goals (SDGs) into the curriculum and assessment woods the learning shift to student-centered, action-learning paradigms. It also encourages collaboration with external partners and bridges the gap between industry practice and scholarly work.

To students, active learning strategies such as debates, reflective tasks, and collaborative group work in the absence of direct instruction foster the acquisition of advanced skills regarding sustainability.

Blended learning such as traditional classroom teachings and online learning helps in creating a very flexible learning environment that also uses technology to tackle or address modern sustainability challenges [7]. This approach fosters an entrepreneurial spirit, professional development, and a holistic perspective [2].

2.4 Standards and accreditation frameworks

The UN SDGs and the National Academy of Engineering's sustainability priorities have underscored the need for engineers to respond to critical global challenges thoughtfully and this need has become urgent [3] [8]. The engineering ethics component of the social and ecological consequences of engineering subject and their inclusion in the ABET accreditation framework still remains a major focus of attention [3] [8]. The most recent engineering competencies development also coincides with the humane aspect of the vision of sustainable development within the circular economy [9].

The impact of the ABET's EC2000, which was to impose a program's ethical competent servicing to the clientele, resulted in the development of creative paradigm shifts in the discipline of engineering ethics [2]. The literature has called for defining specific sustainability competencies, innovative teaching practices, and more involvement with the industry [1]. These are part of the movement to "humanize engineering education," which aims to elaborate the scope of engineering education from the technical to the social, sociotechnical, macroethical, and global responsibility dimensions [1].

2.5 Research design

A descriptive and conceptual research design has been used for this study. The intention is to develop a teaching framework that incorporates the TBL, people, planet, and profit into supply chain education for engineering students without the intention of gathering primary empirical data. The aim of this study is to design a blended model of education based on the integration of various scholarly works, curricula, and teaching methodologies. This type of research is aligned with educational research. Specifically, the type that is more design-oriented, which focuses on the development of frameworks and models as the scholarly contribution to the field.

2.6 Approach to framework development

There are three key phases in the development of the framework, which are as follows:

1. Literature Review: Research pertaining to blended learning, teaching sustainability, supply chain education, and the engineering accreditation standards were reviewed. This phase pinpointed the drawbacks of the lecture format and the problem-based learning approach which blended learning and problem-based learning could use to address the difficulties of sustainability.
2. Synthesis of Best Practices: From the literature, the pedagogical practices of reflective assessment, problem-based seminars, project-based learning, and asynchronous micro-learning were recognized as instrumental in developing student engagement and competencies in teaching sustainability. These were reviewed in relation to the TBL principles and their use in engineering.
3. Integration of the Framework: The layered framework with four integrated and supportive components of asynchronous microlearning, industry-aligned projects, synchronous problem-based seminars, and reflective assessments were developed from the integration of the review and the synthesis. These components were designed to ensure knowledge acquisition and the development of the right mindset with ample time for microlearning, synchronous problem-based seminars, industry-aligned projects, and reflective assessments.

2.7 Theoretical grounding

The framework is grounded in on educational theories and practices, such as:

- Constructivist learning theory which advocates for learner-centered approaches and the active knowledge construction by the learner.
- Problem-Based and Experiential Learning, which highlights the need for theory to be applied in practice to solve challenges relating to supply chain sustainability and other real-world problems.
- Accreditation bodies such as ABET, UNESCO, and the UN SDGs which focus on the integration of ethics, sustainability, and social responsibility in engineering education.

These educational theories provide a firm basis in pedagogy while also ensuring the proposed framework meets international standards in engineering education.

2.8 Validation approach

As this framework remains primarily conceptual, it has not yet been validated empirically in classroom situations. Nevertheless, it derives conceptual validation from the congruence with relevant theories, industry standards, and the literature on best practices. Moreover, even the least resourced universities, in terms of technology and access, will find the framework adaptable to their context.

For future initiatives, it will be important to gather empirical validation by, for example, launching the framework in engineering programs and subsequently obtaining feedback from students and faculty, as well as carrying out longitudinal studies to evaluate the framework's impact on learning and employment outcomes.

3 PROPOSED BLENDED LEARNING FRAMEWORK

3.1 Framework overview

This instructional design seeks to incorporate the elements of the TBL, economic, social, and environmental sustainability into engineering students' education on supply chains. This design also acknowledges that many of the classical approaches to teaching still emphasize the technical aspects of sustainability competencies and neglect the comprehensive sustainability learning gaps. This design embraces the blended learning approach to make the teaching environment more integrated and flexible, thereby helping students to acquire the theoretical and practical competencies needed to address the complexities of sustainability.

This design adopts the theoretical framework of the layered approach; this explains the integrated and interdependent structure of the framework's four elements, which include asynchronous micro-learning, synchronous problem-oriented seminars, reflection on learning, and project work related to the industry. Within this structure, the elements operationalize the integration of self-learning, collaborative learning, applied learning, and reflection. This design was meant to be flexible and scalable and works on the undergraduate as well as the postgraduate level and on the micro level of a single course, right up to a full course.

3.2 Layer 1: Asynchronous microlearning

The first layer emphasizes flexibility and self-directed learning, enabling students to engage with foundational content at their convenience. Learners begin their study on sustainability and the TBL framework through video lectures, readings, interactive content, and online quizzes.

When dealing with limited to no time, it is important and necessary to teach or convey concepts to learners in a manner that is easy to understand and remember [9]. Again, microlearning provides more focused and direct understanding, knowledge, and skills of both smaller and larger concepts, helping learners to grasp knowledge easily and effectively [2]. Using both mobile and digital technologies aids microlearning at any time [10].

3.3 Layer 2: Synchronous problem-based seminars

The second layer focuses on interdisciplinary PBL within the context of synchronous seminars. Regardless of the format, these sessions are designed to engage students collaboratively in the discussion of case studies and problem-situations related to the intricate balancing acts of sustainable supply chain management.

This modality promotes the inculcation of fundamental and higher-order thinking and active learning through developing clarifying questions that are easily addressed in the moment [8].

Authentic problems which require balanced tradeoffs such as cost, carbon emissions, and ethical competitiveness warrant the use of critical thinking and teamwork in problem-solving which are essential for advanced integrated reasoning. Immediate feedback, advanced interaction, and active problem-solving afforded through the synchronous seminars are fundamentals for the collaborative problem-solving skills needed for the supply chain.

3.4 Layer 3: Industry-aligned project work

The third layer extends learning into applied, project-based contexts. Students work on projects jointly designed with industry partners so that they can work on current challenges on sustainability for the projects, which can include assessing renewable energy procurement, circular economy design, and socially responsible sourcing.

The blend of knowledge with practical experience is needed to build the students' "Future Ready" skills so that they can face the challenges that come in the work all over the world.

Aligning with the industry facilitates the attainment of both academic challenge and professional relevance concerning the tasks. Students learn to address real problems holistically, manage different stakeholders, and understand the value and analysis tools used in assessing TBL performance. The scope of these projects helps students realize the relevance and applicability of their learning to the work environment, thus enabling them to assume professional responsibilities with little adjustment.

3.5 Layer 4: Reflective assessment and feedback

It is this last layer of sustaining pedagogy that engages learners in reflection and metacognitive processes regarding the worth and the relevance of the sustainability competences. Critical reflection in relation to the TBL principles of the TBL can be developed by undertaking a range of activities such as essays, journals, and portfolios.

Many scholars have thoroughly investigated how reflective assessment and feedback are essential for learning and for developing metacognition and pedagogy involving guided self-assessment, feedback, mentorship, and other structured tools designed for self-regulation and critical thinking [11]. Studies of ChatGPT in higher education similarly demonstrate its capacity to deliver instant feedback, improve writing and reasoning skills, and enhance student engagement through accessible AI-driven learning [12], [13]. [2] references and highlights that these innovative tools introduce transformative approaches to providing feedback that is instant, tailored, and abundant.

Rubric, a scoring tool used in evaluating students work is largely based on approved outcomes, criteria (technical, ethical, social) and performance to ensure they meet the stated standard.

3.6 Scalability and adaptability

This framework functions equally well in different social settings. Basic sustainability principles could be taught in individual modules at the course level. At the program level, however, the four layers could be embedded in the entire curricula enabling continuous and progressive development of sustainability competencies.

3.7 Expected learning outcomes

With this structure, we expect students to reach:

- Knowledge: Profound comprehension of TBL principles and their application concerning supply chains.
- Skills: Proficiency in quantitative analysis and trade-off decision making, sustainability collaboration and project management.
- Attitudes and Values: A true advocate of sustainability with an ethical approach to social justice and equity, as well as being an environmental systems thinker.

4 DISCUSSION: INSTRUCTIONAL TOOLS AND TECHNOLOGIES

Emerging tools are transforming creative workflows and knowledge generation in educational and organizational contexts, enabling educators and students to co-create learning innovations [14].

As learning management systems (LMS) sustain the backbone of delivery systems, the use of multifunctional cloud-based systems reinforces students' understanding of the application of the environmental dimensions concerning sustainability in supply chain decisions.

Through collaborative drafting of models and industry-standard reports under the governance of version control systems and shared drive documents with LMS, students report enhanced learning outcomes. Students are also supported throughout the use of video conferencing systems with breakout rooms, allowing guests to connect theory to practice through problem and colleague discussions.

4.1 Assessment strategy

Learners are assessed regarding the integration of the social, environmental, and economic balances in their decisions.

In the formative assessments (quizzes, problem sets, case discussions, and discussions), the synch activities include peer and instructor feedback as well as case auth depiction. These assessments provide the opportunity for cooperative and collaborative knowledge integration and closure.

The summative assessments stress the application of the TBL in the 'real world,' with the learners addressing the sustainable and innovative solutions for supply chain management in their industry-aligned reports, presentations, and portfolios. The scoring guides focus analysis and depth on sustainable supply chain management.

4.2 Implementation example 12-week module outline (high-level)

The proposed blended learning framework was applied to construct an example of a 12-week module. This outline shows a sequence where the four inter-paired layers of micro-learning, synchronous seminars, industry-aligned projects, and reflective assessments are designed to progressively strengthen the incorporation of TBL supply chain principles and captured TBL principles education into engineering education.

The module aims to achieve a balanced framework of knowledge acquisition, collaborative engagement, and applied practice followed by a period of reflection. At the start of this course, the learners will cover the principles of sustainability within the TBL framework. In weeks five to eight, the enrollees undertake industry-focused, applied problem-solving projects to gain hands-on experience with actual supply chain issues. The final four weeks are for integration and reflection, during which the students combine their learned skills to share and peer review project work.

This sequence contributes to students learning progressively complex concepts and completing tasks, all the while reflecting on the learning outcomes. The module is flexible and can fit different institutional environments and can be designed for undergraduate or postgraduate students, increasing or decreasing the depth and complexity of the material.

Table 1. 12-week module outline

Week(s)	Focus Area	Learning Activities	Assessment Elements
1–2	Introduction to TBL and sustainability in supply chains	Asynchronous micro-lessons; quizzes; introductory seminar	Online quiz; participation
3–4	Systems thinking and trade-offs in sustainable supply chains	Case study discussions in synchronous seminars; collaborative modeling	Group work
5–6	Applied problem-solving	Introduction to industry-themed project; team formation; project scoping	Project proposal (formative)
7–8	Project development	Team-based project work with faculty and industry feedback	Mock project report
9–10	Integration and synthesis	Reflective journaling; peer review; social and environmental seminars	Reflective journal submission
11–12	Presentation and evaluation	Capstone project; peer feedback; synthesis seminar	Final project presentation

This outline shows that the blended framework can be applied within a standard semester schedule. It reflects a deliberate combination of asynchronous learning, synchronous collaboration, applied projects, and reflection. The careful order of these activities ensures that sustainability principles are combined throughout the learning experience instead of being presented as a hidden or additional topic.

4.3 Scaling, equity, and inclusivity considerations

The framework's core is built on the principles of equity and inclusivity by combining asynchronous sessions with microlearning and other formats alongside real-time responsive activities addressing various preferences and time constraints.

Cost-effective and open-access approaches and tools are endorsed to enhance accessibility and lessen fiscal imposition. It aligns various teaching methods on the same instructional design to neutralize oversimplified and unipolar conclusions. The sustainable interdependence framework focuses on collaboration for real-world group projects to promote global sustainability competencies. A balance between equity and scalability fosters inclusivity.

4.4 Evaluation and continuous improvement

The effectiveness and relevance of the proposed blended learning framework depend on systematic appraisal and the provision of continuous improvement activities, which must be carried out to ensure the sustainability of supply chain education as an integrated and continuous discipline. AI-driven analytics and generative tools can further enhance such evaluation cycles by identifying creative learning trends and supporting data-informed pedagogical refinement [14]. The framework's design also incorporates evaluative feedback loops that allow educators and educational institutions to rapidly implement adjustments in content, methodology, and assessment in relatively short periods.

Course evaluation starts with and focuses on students, using feedback surveys, reflective journals, and focus groups as a means of data collection. The blended learning framework constituent elements are approximated and gauged, while students' enthusiasm in problem-based seminars and challenges provides sparks of success; logistical challenges in accessing the requisite digital devices flag areas that need attention.

Instructors primarily function as teachers, although at this level, the evaluation of teaching and learning is strengthened by the addition of peer reviews. Faculty collaboration facilitates determining the alignment of teaching materials, class activities, and evaluation tasks with the stated learning outcomes, as well as the exchange of innovative collaboration practices. The principles of collaboration and peer review would, however, require further clarification.

As stated earlier, collaboration leads to the redesign of the instruction, which is the modernization of the activities of teaching and learning.

5 CONCLUSION AND FUTURE WORK

This paper presented a blended learning framework to integrate the three components of the TBL—economic, social, and environmental—into supply chain education for engineers. To address the challenges of unpreparedness, the framework includes asynchronous micromodules, live problem-based seminars, industry-linked projects, and directed reflection. This allows for a multi-layered delivery of the essential technical skills and sustainability awareness that graduates need in modern supply engineering.

Better alignment of programs with relevant industry sectors will help improve graduate employability and strengthen academic–industry partnerships. Increased opportunities for reflective learning will further support the growth of citizenship and ethical maturity.

Currently, the framework supports the institution in meeting accreditation standards while incorporating the UN SDGs to address global expectations. For industry partners, it ensures that future employees possess the necessary technical, ethical, and systemic competencies. The framework's sustainability is built on four key pillars: prepared faculty, institutional support, suitable technology, and equitable access.

In subsequent studies, the proposed work will enhance empirical research in this area by investigating the framework in various educational settings and longitudinal studies on students concerning outcomes and pathways to industry relevance. The implementation will continue to be enriched by emerging technologies and deepened collaboration with industries and policymakers. In particular, the creative potential of AI to foster innovation, experimentation, and reflective learning represents a vital frontier for future engineering pedagogy [14].

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