ENGINEERING LEARNING OF SUSTAINABLE PRODUCT LIFECYCLE THROUGH CDIO

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ABSTRACT

Sustainable development is an optional CDIO (Conceive, Design, Implement, Operate) standard in the engineering curriculum, however, due to the impact of climate change on society and the environment, sustainability is now seen as a crucial aspect of learning. Engineering has contributed to climate change through non-sustainable solutions, so it is important to implement a sustainable CDIO standard in the engineering curriculum. In the UK, the Engineering Council already requires engineering-accredited courses to embed sustainability into the engineering curriculum, learning, practice and assessment in accordance with the UNESCO sustainability goals. This means that the engineering curriculum is required to provide learning opportunities for students to engineer sustainable solutions that are fit for all of society.   This paper illustrates how the optional CDIO standard: sustainable development has been implemented in a second-year capstone project module The module challenges students to research and develop a low-carbon footprint product for World Rugby The module placed learning emphasis on a diamond TQM+ paradigm (Time, Quality, Management, Sustainability, Health & Safety) and challenged students to consider environmental impact and circular economy solutions. The paper reports on student learning, challenges, and successes in satisfying this diamond TQM+ paradigm to engineer sustainable rugby equipment (products, clothing, footwear, PPE) solutions and opportunities for further student learning development.

KEYWORDS

Engineering Education, Capstone Project, TQM+, UNSECO Goals, Earth Charter, Optional Standard: Sustainable Development

INTRODUCTION

Malmqvist et al (2017) demonstrated that there is a clear need for engineering graduates to have competencies in sustainable development, this was further developed by Malmqvist et al (2019) and recommended by Malmqvist (2019) for adoption by CDIO Council as optional CDIO standard sustainable development.   Rosen et al (2021) reported on the pilot implementation of the optional standard and assessment rubrics to be used when implementing optional CDIO standard sustainable development as a starting point for implementation in the curriculum. Dubova et al. (2020) embedded this optional standard into metallurgical education to challenge students to consider and justify material selection in CDIO projects on sustainable considerations.

In reality, any CDIO project students have historically been challenged at the concept and design stage to consider the time (manufacture/fabricate), quality (fitness to requirements) and cost (materials and manufacture), Clausen (2018) highlighted that CDIO projects have the opportunity encapsulate TQM and Lean Management. However, TQM and Lean Management neglect sustainability and safety considerations. Hamdan et al (2021) demonstrated the adoption of more manufacturing corporate social responsibility (CRP) focus enables a business to address and align different TQM and Corporate Green Performance (CGP) considerations. Santos et al (2019) safety management systems (SMS) can be adopted well under a TQM approach in particular to address unsafe working conditions, (Álvarez-Santos, 2018). However, safety is an important consideration at each stage of the CDIO project to generate a new product, addressing the safety from an end user perspective at conceiving, designing and operating a new product, also safe manufacture and fabrication at the implementation stage. This has been very much taken to heart by the construction industry as safety is part of construction site TQM strategy leads to improve quality of construction in terms, also site planning, organization, coordination, and profit, (Husin, 2008).

Adopting the TQM approach with a focus on producing quality products in a safe approach and applying environmental and societal considerations can increase a business's bottom line (Mohan et al, 2004), Therefore for businesses not only on moral and ethical grounds a Time, Quality and Management (TQM+) diamond paradigm approach offers a more sustainable business economic health than traditional TQM triangle. As engineers conceive, design, implement and operate new products for a business, the next generation engineers need learning opportunities to apply the TQM+ diamond paradigm considering during a CDIO project the;

- time to produce and recycle,
- cost to manufacture, deliver, recycle/end of life,
- quality of the processes and product lifespan
- health and safety of the product, manufacture and recycle/end of life,
- sustainability resources, materials products and recycling/end-of-life.

This paper will illustrate how the optional CDIO Standard: Sustainable development and facilitating the students to adopt a TQM+ diamond paradigm approach enabled the students to address conceiving, designing, implementing, and operating a low carbon footprint product for World Rugby. The students were challenged to research rugby equipment (products, clothing, footwear, PPE), and identify opportunities for product improvements or opportunities for new products within the World Rugby equipment performance constraints. The students were challenged to CDIO new products in terms of time (produce), quality (lifespan of the product), management (costs both in terms of financial and carbon footprint), sustainability (sustainable raw materials, manufacture process and end-of-life (recycle/reuse)) and health & safety (as PPE). Essentially challenging the students to conceive, design, implement and operate new Rugby PPE products that satisfy the TQM+ diamond paradigm. The paper will report on student learning, challenges, and successes in satisfying the diamond TQM+ paradigm to engineer sustainable rugby equipment (products, clothing, footwear, PPE) solutions. Identifying in particular, where students demonstrated learning well in engineering sustainable solutions. It also illustrates the aspects of the product lifecycle design and implementation that the students found challenging, which is difficult for students to research and complete and therefore requires further student learning development.

PRODUCT LIFE-CYCLE MODULE

The module aims to provide students with an overview of complex product life cycles from raw materials to end of life taking into consideration the wider social, environmental, business and financial contexts of the engineering solution and the role of a professional engineer operating within the field of mechanical related engineering, with particular attention to their legal, safe and ethical responsibilities. The module learning outcomes, the students by the end of the module should be able to:

1. Apply appropriate design methodology, engineering analysis methods and engineering management to conceive, design, rapid prototype/simulate and evaluate the operation of a heuristic product solution;

2. Evaluate data and solve basic fiscal and engineering mathematical computations/modelling to support a conceptual engineered solution for a problem typically sourced from the industry;

3. Produce technical data sheets and drawings to support the manufacture and assembly of a product using a computer software tool; and

4. Understand the wider legal, social, political and ethical context of a product and its lifecycle and the professional responsibilities of the engineer.

The module was designed to build upon the student's first-year learning and in particular first-year capstone project module, providing an opportunity for students to develop and apply their technical and non-technical skills to solve a mechanical engineering-related problem typically sourced from the industry. The module approaches developing these skills through a process of engineering in practice, continuous professional development (CPD) and assessment for learning. The students are to undertake a lifecycle and risk assessment study project in pairs or a team of students.

The projects are identified by industry in this case on the behalf of Rugby federation to examine opportunities for more sustainable Rugby PPE. Students are challenged to identify what has the potential to be improved on sustainability grounds Rugby PPE, students are encouraged to examine in detail and map out the life cycle of the product. The groups are encouraged to break the product down into its principal components and trace them back to the raw materials and likely country of origin. The students are encouraged to select a product that currently has significant health, social or ethical aspects associated with at least one part of their manufacture. The students are to conceive, design, implement and operate more sustainable product solutions.

The students throughout the project explore the engineering design methodologies, design thinking, systems thinking from engineering design, material selection, simulation/prototype and evaluate the operation of the product taking into account health and safety, commerce, sustainability and business management considerations, essentially diamond TQM+ paradigm. They are also required to consider the users of the product and how it might be made more suitable for different groups of users, for inclusive solutions for all of society. The students present their final results and personal reflections on the project in the form of a presentation and report illustrating the estimation of raw material costs, health and safety, end-of-life environmental impact etc.

The module provides a learning opportunity on the full engineering product or systems lifecycle, the role of other professionals and processes in the product lifecycle for example the engineering industry and government(s), marketing, finance (cost estimation, budgeting and forecasting), environment, efficiencies, end of life, carbon footprint, maintenance, sustainability, ethics, risks, hazards, health and safety.

MODULE RESULTS

The students pursuing different degree pathways such as Biomedical, Mechanical and Product Design engineering were given the freedom to pick and research their problem which led to interesting choices which may not have resulted if a specific problem was provided to them. Multiple research projects were carried out in understanding the lifecycle of rugby balls (Figure 1), materials used in the shoe upper (excluding the sole) (Figure 2), tackling and scrum training equipment, PPE such as Headgear and Shin pads, and some biomedical students even looked at mouthguards and wheelchair rugby.

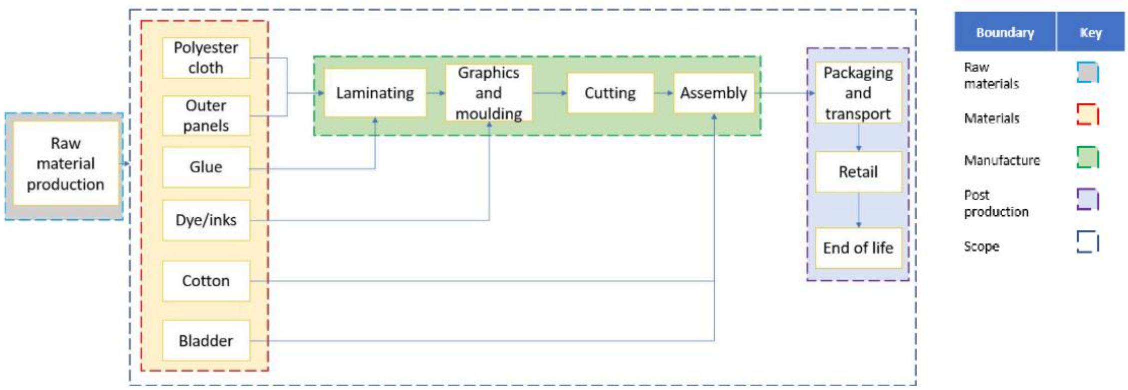

Figure 1: Scope of the lifecycle analysis carried out by the students studying rugby balls.

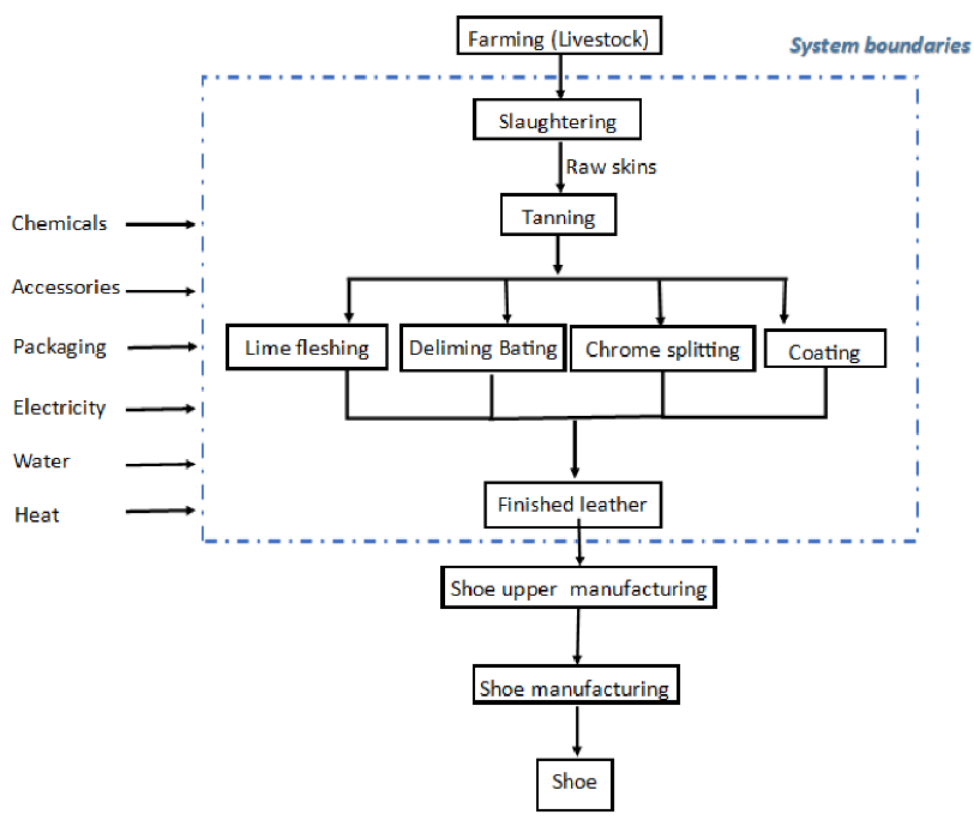

Figure 2:System boundaries for the study of leather used in making shoes.

Comparisons between materials for different equipment were presented to understand the change they would create on the environmental impact. One group of students studying the rugby ball reported an increase of 31% in the carbon footprint when comparing a synthetic rubber ball (Butyl) to a natural rubber rugby ball (Figure 3).

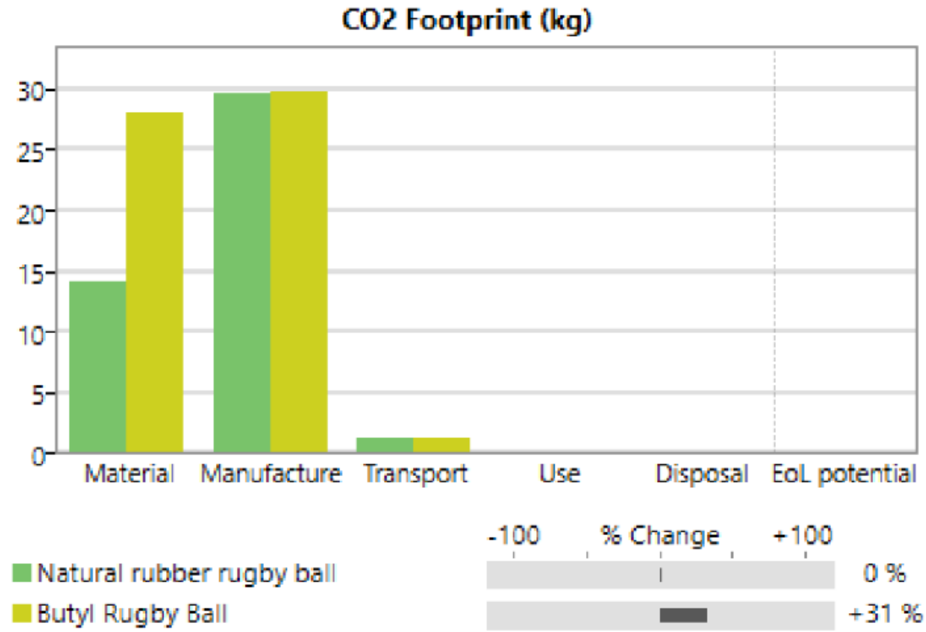

Figure 3: Student carbon footprint comparison for a Butyl rugby ball in comparison to a natural rubber rugby ball.

Students researching the lifecycle assessment of the mouthguards included comparisons for the different potential materials' physical properties such as toughness/hardness, impact test properties and performance against bacteria and porosity for permeation of saliva. Students researching the scrum caps produced an interesting read on the amount of CO2e used/emitted during the lifecycle of a headgear made out of EVA (Table 1). Results show that almost 98% of the impact on the environment came from the use of water.

Table 1: Values of CO2e for lifecycle analysis of a Rugby headgear made of EVA

Property	**Value (gCO2E)**
Primary Embodied Energy	298.78
Primary Material CO2 footprint	289.85
Polymer Moulding	64.53
Water Usage	69207.00
Material Processing	93.50
Recycling and Combustion	358.40
	70312.06

Students studying the padding material used in the body padding reported that: "*A change in foam to an eco-friendlier option known as eco-foam, this option reduces the CO2e impact by 14% and is fully recycled and recyclable*".

From the academic perspective, the numbers obtained for students' performance are shown in Table 2. The results for individual assessment show a 91 % first-time pass rate while the take-home exam shows a 90 % first-time pass rate. The overall pass rate for the first-time sit is 89 % which is higher than the UK norms.

Table 2: Pattern of student grades following the 4 assessments – 3 coursework and 1 exam

	Coursework	Exam	Overall
Min – Max	15-84	8-96	12-85.5
Mean	57.8	63.75	55.75
Standard Deviation	17.6	22.7	19.2
Pass %	91	90	89

MODULE RESULTS DISCUSSION

One of the first findings of this module CDIO project was that the students enjoyed having their area of focus and research. As the module assessments were set up the assessment brief provided to the students allowed the students to pick and choose a CDIO project that is related to rugby. This allowed the students a bit more leeway in choosing a rugby product that would be more aligned with their degree. The biomedical engineering students were able to pick research studies focused on injury prevention such as mouthguards or even looking at Paralympic rugby where the students focused on wheelchairs used in wheelchair rugby. Usually with a CDIO project, when sourced from industry, the problem statement is already defined under students have a limited scope under which they carry out their learning and research. allowing a student to pick their project as done in this study provided them with the challenge of conceiving the problem. The students had to look at the product not only from an environmental perspective but also to try and gauge what improvement could they do to ask to improve the performance of the product as well as reduce its impact on the environment.

Work done by the students shows an increase in their understanding of life cycle assessments add and perception of the pact of engineering on the environment. Some of the reports submitted highlighted the learnings of the students, where the students identified that for certain products the use of water is the highest contributor to the environmental impact. This led to the identification of other products and processes, such as everyday clothing and the washing/laundry pattern, which the students use, and the realisation of the environmental impact everyday activities may have. The learnings from the project have helped students understand not only the implications in design and manufacture but also have understood the implications in their daily life.

As part of the module, the students, under the guidance of the technical team, also used energy meters (PM001-C, Maxcio, Ningbo Qiyue Electronics Company LTD, China) to understand the carbon footprint of different components/processes in a manufacturing setup/process. During the experiments, students were able to calculate total power usage that was then converted to GHG emission equivalency. During the experiments carried out, while looking at all the energy consumption the students were able to relate to the energy wastage that occurs and identify sources of energy losses. The students were also able to correlate the energy losses noted by comparing them to their experiences with the increase in energy bills in the UK.

Along with all the positive learning outcomes, there was a lot of feedback from the students which would help improve the Engineering Product lifecycle module in the long run. The main feedback received was "*More hands-on working to be provided to improve engagement*". The other feedback received at the end of the module review survey was: "*More hands-on practical sessions would be beneficial as it was mostly sitting in a classroom on a computer*". The module content is comparatively more theoretical than other traditional engineering modules such as material testing, machine shop, and computer-aided design.

The module team has worked on the feedback received and has carried out more statical research this year to understand how student engagement can be improved. To improve student interaction, not just in the classroom but also with the module documentation, I am going to try and incorporate different methods of signposting information- through emails, announcements and interactive quizzes while monitoring the interaction information to gauge what works best. In the past, the author has noticed an increased enthusiasm and animated discussion whenever a little quiz or competitive questioning is carried out (O'Neill, 2020; Zhang & Yu, 2021). The module teams also plan to carry on investigating different techniques used by other researchers and academics to enhance student engagement and also understand what student engagement might look like rather than just hours spent on the module website (Hu & Li, 2017; Kennedy, 2020).

The work done by the students resulted in an improved understanding of the impact of engineering on the environmental impact of the product. The layout of the assessments-coursework showing the planning and the report presenting the final work also provides the students with a logical approach which helps them obtain feedback and provides a structure which supports engaged learning and systematic improvement in the quality of the work produced. The strategies followed in this module have been shown to provide the students with an experience to not only Design, Implement and Operate the solution but also focus on Conceiving the problem. This holistic CDIO approach has led to students improving the existing engineering solutions for able-bodied and Paralympic rugby while also improving its impact on the environment. This project has helped the students understand the implications of cost, quality, processing, packaging and transport, logistics of materials and overall production which impacts the end product and its sustainability.

CONCLUSION

The engineering product lifecycle module has been shaped to allow students to pick a product in Rugby equipment (products, clothing, footwear, PPE) to analyze and improve its design with an eye on the sustainability of the product by carrying out a lifecycle analysis. Through this year-long module, the students have analyzed different rugby products such as rugby balls, shoe leather, studs, body padding, scrum training equipment and other PPE such as shin pads and scrum hats. The students were able to analyze different energy uses during a manufacturing process and convert it to emissions in the form of CO_2e. The students have produced detailed reports on different solutions for each problem and produced comparisons which show how the changes or improvements have affected the sustainability of the product. The student solutions balancing the TQM+ diamond paradigm satisfy the tangible considerations of:

- time
- cost
- quality
- health and safety
- sustainability

The findings from the module also show that students can relate the findings of their research to their personal lives and other projects. The module team will keep running the project for a couple of years to provide the students with an opportunity to select a project and analyse it to satisfy the diamond TQM+ paradigm.

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