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Mapping Sustainable Development in Engineering Curricula

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ABSTRACT

Context

The importance of sustainable development (SD) in engineering curricula has grown considerably over the last decade. Many engineering faculties and departments recognise this importance but struggle to address sustainable development content in individual subjects. Before efforts can be made to renew engineering curricula and include these concepts, a baseline must be established.

Purpose/ Goal

In this context, this paper aims to demonstrate a novel method for mapping the presence of sustainable development concepts in engineering curricula using publicly available information. By mapping the presence of these concepts, educators can highlight where improvements can be made to include sustainable development in the curriculum. This mapping method can be used in any engineering discipline.

Approach/ Method/ Methodologies

Three types of data were collected: a degree course plan, sustainable development keywords, and subject outlines/ handbook entries. The list of SD keywords was developed through a literature review. Information about individual subjects was extracted from the publicly available university ‘Handbook’ online. The presence of SD concepts was analysed to form a ‘heat map’.

Actual / Anticipated Outcomes

The Masters of Chemical Engineering degree at the University of Melbourne was used as a case study for this method. The case study found that sustainable development concepts are present throughout most of the curriculum, but the concepts are absent in one semester.

Conclusions/ Recommendations/ Summary

This mapping method is shown to quickly and visually demonstrate where sustainable development is present in the engineering curriculum. While chemical engineering was used as a case study, the method can be applied to any engineering discipline. This map is significant as it helps build a foundation for improved educational outcomes for students and the next generation of engineers. The results from the case study indicate that sustainable development is present in much of the chemical engineering curriculum. This presence provides students with opportunities to develop sustainable development competencies and capabilities required of chemical engineers.

KEYWORDS

Sustainable Development, Competency Mapping

Introduction

Our future engineers need to be equipped with the capabilities to solve sustainable development issues, and these capabilities should begin being developed in formal engineering education. Developing these capabilities requires sustainable development concepts and principles to be present and integrated into the engineering curriculum. Effective integration of these concepts requires the current state of sustainable development teaching to be assessed first. This assessment establishes a baseline and proposes future improvements to the curriculum.

The Brundtland Commission defined Sustainable Development (SD) as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). It is also commonly referred to as the ‘road’ towards the end goal of sustainability. The three pillars of sustainable development, environmental, social, and economic, also sit within the sustainable development paradigm, as do the United Nation’s Sustainable Development Goals (SDGs).

Sustainable Development and the SDGs are increasingly referenced in many areas of education, including engineering education. The recently ratified September 2021 International Engineering Alliance Washington Accords now include specific mention of sustainable development and the SDGs (IEA, 2021). Therefore, it is not unreasonable to expect Engineers Australia’s next Stage 1 Competencies to also require the inclusion of sustainable development and the SDGs for accreditation. The importance of sustainable development in engineering education will only increase with time: it’s best to act now to integrate sustainable development into the engineering curriculum.

Education for Sustainable Development (ESD) is the paradigm encompassing the entire education system and its relationship to sustainable development. Engineering Education for Sustainable Development (EESD) is a sub-field of ESD and is concerned exclusively with how engineering education relates to sustainable development.

Literature Review

The mapping of sustainable development in engineering curricula is an emerging theme in the literature as more faculties assess and improve how they teach these concepts. This mapping assesses where sustainable development (concepts, competencies, or capabilities) is present in the engineering curriculum. Depending on the institution, curriculum data is based on publicly available information such as subject outlines or university ‘handbook’ entries (Gómez-Martín *et al.*, 2021; Sánchez-Carracedo *et al.*, 2019). Some studies also use additional data like educator surveys (Lamere *et al.*, 2021; Rajabifard *et al*., 2021; Sánchez-Carracedo *et al*., 2021) or assessment material (Trad, 2019).

The sustainable development mapping basis varies in the literature. The SDGs (Gómez-Martín *et al*., 2021; Rajabifard *et al*., 2021) and related competencies (Sánchez-Carracedo *et al*., 2021) are commonly used, as well as generalised ESD competencies (Lamere *et al*., 2021; Trad, 2019) that should be developed by all learners (Rieckmann, 2017). Other bases include SD competencies developed by Spanish university leaders (Galofré & Segalas, 2021; Sánchez-Carracedo *et al*., 2019, 2021), and discipline-specific SD competencies. Mappings of discipline-specific SD competencies are rare in the literature but exist for mechanical engineering (Enelund *et al*., 2013) and civil engineering (Woolschlager, 2013). The presence of sustainable development concepts themselves is rarely used as a mapping basis.

Most mapping studies compare degrees rather than individual subjects within a degree (Rajabifard *et al.*, 2021; Sánchez-Carracedo *et al*., 2019, 2021; Trad, 2019). Degree comparison is valuable information for faculties and universities looking for trends. However, this analysis does not provide the details needed for individual educators to make the necessary changes to improve student outcomes in a single degree. Several papers analyse individual degrees (Galofré & Segalas, 2021; Gómez-Martín *et al*., 2021), but do not show sustainable development spread across the engineering curriculum. Enelund *et al*. (2013) studied the presence of mechanical engineering sustainability competencies in the curriculum of a post-graduate mechanical engineering degree. However, this study does not use publicly available information and is difficult to replicate without a list of discipline-specific sustainable development competencies or capabilities.

Most mapping studies found the inclusion of sustainable development in the engineering curriculum was below a level deemed acceptable by the authors (Gómez-Martín *et al.*, 2021; Rajabifard *et al.*, 2021; Sánchez-Carracedo *et al.*, 2019; Trad, 2019; Woolschlager, 2013). This low level shows that while many universities and engineering faculties strive to address sustainable development, this effort is not always translated into subjects. However, the literature has not agreed upon an ideal or target 'level' of inclusion. This gap makes the assessment and comparison of degrees difficult.

This paper presents a process for educators to quickly assess the presence of sustainable development concepts in the engineering curriculum and thus highlight gaps and areas for future improvement. The novel mapping technique is based on publicly available information and researcher expertise and produces a map showing where sustainable development is being taught in the curriculum. The recently renewed Masters of Chemical Engineering at the University of Melbourne was used as a case study to test this method.

Method

This study was performed to contribute to improved educational outcomes for engineering students and therefore aligns with the Pragmatic research paradigm. As such, the most appropriate methods were selected to complete the study, i.e., to assess the presence of sustainable development in the engineering curriculum.

This study aims to answer the research question:

Where are the concepts of sustainable development present in the engineering curriculum, and where are the gaps?

To answer this research question, a process to map the presence of sustainable development in the engineering curriculum was developed. This process was applied to the Masters of Chemical Engineering (MoCE) at the University of Melbourne as a case study. While this paper focuses on chemical engineering, the method can be applied to any engineering discipline.

The mapping process compares three types of information to produce a map of sustainable development presence in the curriculum: the degree course plan, handbook entries/ subject outlines for all included subjects, and a list of the appropriate sustainable development keywords representing SD concepts. SD keywords in the subjects' handbook entries were analysed and compiled to produce a 'heat map' showing where sustainable development is taught in the curriculum.

While the inclusion of concepts, integration of concepts, and development of capabilities are all important aspects of teaching and learning, only the inclusion of concepts was assessed in this mapping study. Integrating concepts into a subject requires more detailed and verifiable information than can be provided by handbook entries, e.g., teaching materials. The development of SD capabilities is a complex area, and the selection of appropriate discipline-specific SD capabilities is even more so. A list of sustainable development capabilities for chemical engineering does not currently exist, and compiling one is outside the scope of this study. Based on the inclusion of concepts, the resulting map is more straightforward than one based on the integration of concepts or capabilities but provides a foundation for these to be mapped in the future.

This method has the advantages of requiring little time or resources and no ethics approval. But, as with any method, it does have its limitations. The quality of the outputs is based on the quality and quantity of information provided by the handbook entries. This relationship means that any misalignment between the handbook entries and what is taught in the subject will affect the final map produced. This misalignment can occur when sustainable development concepts are taught in a subject but not included in the handbook. It can also happen when subjects claim to teach sustainable development but do not address the concepts in the curriculum. Efforts have been made to limit the impact of mis-claimed sustainable development inclusion and are discussed below. However, the detection of mis-claimed SD inclusion is outside the scope of this paper. Such detection would require analysis of teaching and assessment materials, as seen in Trad (2019).

Data Collection

Three types of data are required for this process:

- Engineering degree course plan and a list of all included subjects
- Handbook entries/ subject outlines
- List of sustainable development keywords

The case study used the course plan of the recently renewed Masters of Chemical Engineering, including specialisations (Business, Materials and Minerals, Sustainability and Environment) and elective subjects offered by the Department of Chemical Engineering. The University of Melbourne provides an online ‘handbook’ for students that outlines information on the content for all subjects offered by the University. The handbook entries are comprised of four sections: Aims, Indicative Content, Intended Learning Outcomes, and Generic Skills. Not all entries include all four sections, but most will generally have three of the four. A list of sustainable development keywords was developed through a literature review. These keywords centred on the main themes of sustainable development, e.g., “sustainable” and “sustainability”: an abbreviated list can be found in Table 1. This list was developed at the start of the data collection stage and revised through the data analysis stage to ensure the appropriate phrases were included and excluded. While efforts were made to keep the keyword list general to all engineering disciplines, some keywords relevant to chemical engineering may not apply to every engineering discipline. The relevance of keywords highlights the importance of the researcher bringing their discipline-specific context to the mapping of sustainable development.

Table 1: List of keywords used to analyse handbook entries by Qualitative Data Analysis

“Sustainable”-based keywords and phrases	“Sustainability”-based keywords and phrases
Sustainable	Sustainability
Sustainable Design	Sustainability Issues
Sustainable Development	Sustainability Principles
Sustainable Engineering	Sustainability of Resources
Sustainable Processing	Sustainability Requirements
Sustainable Production	Process Sustainability

Data Analysis

The handbook data was analysed using Qualitative Content Analysis (QCA). The presence of the keywords was the first step in the content analysis, but the second step considered the context of the words. For example, “sustainable” when paired with “development” was included but excluded when paired with “business competition”. The first pair relates to the paradigm of sustainable development, but the second refers to business practices.

The content analysis was performed in four rounds of analysis (referred to as “coding” in the method) using the QCA software Dedoose.

- Round “0”: Pre-reading data, becoming familiar with structure and content
- Round 1: Coding keywords and noting developing patterns
- Round 2: Verifying Round 1 and coding for patterns noticed in Round 1
- Round 3: Coding subjects based on categories to produce heat map data

Three categories were used to describe the evidence of a subject including or not including sustainable development in its handbook entry (described in Table 2). Binary data is easily analysed but over-simplifies the complex topic of sustainable development. Additionally, binary data risks including subjects that mis-claim the inclusion of sustainable development.

Subjects in the “weak” category met one of two criteria. Firstly, the subjects only referenced SD concepts in the “Generic Skills” section of an entry, with no evidence in the rest of the entry that those skills are developed. Secondly, the subjects only discussed the economic pillar (via cost estimation) or the social pillar (via communication requirements), and therefore do not have evidence of addressing the overarching concept of sustainable development. No subject entries referenced the environmental pillar without addressing overarching sustainable development concepts.

Based on these categorisations and the course structure, a ‘heat map’ showing the presence of sustainable development concepts in the curricula of different subjects was developed (see Figure 1).

Neither the Department of Chemical Engineering nor the literature has articulated a target level of inclusion of sustainable development. This lack of target makes drawing conclusions difficult. However, the concept of safety is similar to sustainable development. Safety is considered an integral principle of chemical engineering and is therefore integrated into all chemical engineering subjects. Given the assumption that safety is ubiquitous in the chemical engineering curriculum, the concept of safety acted as a benchmark. As a benchmark, it served as a comparison to the level of sustainable development in the chemical engineering curriculum. Other concepts, such as communication or teamwork, could also be used if a target level of inclusion has not been articulated.

Table 2: Legend and description of categories for subjects in the heat map.

Strong	Weak	None
The subject entry has clear evidence of including SD concepts	The subject entry has weak evidence of including SD concepts	The subject entry has no evidence of including SD concepts

Results/ Discussion

It was found that the above process does produce a practical heat map showing where sustainable development is present in the engineering curriculum. Figure 1 below shows the heat map from the Masters of Chemical Engineering case study.

The heat map developed for the case study shows that sustainable development is present throughout most of the chemical engineering curriculum. Sustainable development content is present in all three years of the degree as well as the capstone (CHEN90022) and capstone-adjacent subjects (CHEN30015, CHEN90020, CHEN90013). As sustainable development is continually addressed throughout the degree, students will likely develop sustainable development capabilities. However, further study is required to verify and articulate these capabilities.

Semester 3, however, shows a gap: there is only weak evidence that sustainable development is addressed during the four subjects that make up the semester. This gap presents an opportunity for these subjects to be updated and address sustainable development.

	Semester 1	Semester 2
Y1	Fluid Mechanics (ENGR30002)	Engineering Mathematics (MAST20029)
	Materials and Energy Balances (CHEN20010)	Digitisation in the Process Industry (CHEN20011)
	Fundamentals of Chemical Engineering (CHEN20012)	Momentum, Mass and Heat Transfer (CHEN30016)
	Engineering Communications (ENGR90021/ ENGR90034/ ENGR90029)	Safety and Sustainability Case Studies (CHEN30015)
	Semester 3	**Semester 4**
Y2	Chemical Engineering Thermodynamics (CHEN90007)	Design and Construction of Equipment (CHEN90012)
	Thermal Separation and Design (CHEN90042)	Chemical Engineering Management (CHEN90020)
	Reactors and Catalysis (CHEN30001)	Specialisation/ Elective
	Specialisation/ Elective	Specialisation/ Elective
	Semester 5	**Semester 6**
Y3	Process Engineering (CHEN90013)	Chemical Engineering Design Project (CHEN90022)
	Process Simulation and Control (CHEN90032)	
	Chemical Engineering Research Project or Internship (CHEN90028 / CHEN90023)	Specialisation/ Elective
		Specialisation/ Elective

Business Specialisation	Sustainability and Environment Specialisation	Materials and Minerals Specialisation	Electives
Strategy Execution for Engineers (ENGM90013)	Sustainable Processing (CHEN90031)	High Performance Materials (CHEN90043)	Product Design and Analysis (CHEN90038)
Marketing Management for Engineers (ENGM90015)	Wastewater and Environmental Remediation (CHEN90011)	Particle Technology (CHEN90018)	Pharmaceutical and Biochemical Production (CHEN90039)
Engineering Contracts and Procurement (ENGM90006)	Energy, Emissions and Pollution Control (CHEN90041)	Sustainable Minerals and Recycling (CHEN90010)	Sustainable Food Processing (CHEN90040)
			Future Fuels and Petroleum (CHEN90027)

Figure 1: Heat map showing the inclusion of sustainable development in the Masters of Chemical Engineering degree at the University of Melbourne. Double-sized cells represent subjects worth two-subjects credit points. A link to a sample subject in the University Handbook can be found here.

Looking at the whole degree, 42% (14/33) of all subjects have strong evidence of including sustainable development concepts. But this percentage drops to 35% (7/20) when only considering core subjects (excluding specialisations and electives). Unsurprisingly, the Sustainability and Environment specialisation had the highest level of sustainable development presence. The Business specialisation only referenced the economic pillar. Despite these relatively low inclusion statistics, sustainable development is still spread through most of the Masters of Chemical Engineering curriculum.

But these statistics need to be compared with the target level of inclusion: the safety benchmark. There is more evidence of sustainable development inclusion than safety in the handbook entries.

Only 30% (10/33) of subjects have evidence of including safety in the handbook entries. On the surface, this shows that sustainable development is heavily included in the chemical engineering curriculum. But the comparison is more complex than that. This 30% does not mean that safety is not included or integrated into chemical engineering subjects: it means that safety is not included in the handbook entries for these subjects. This is likely because safety, being so ubiquitous, is already assumed to be integrated into a subject and does not need to be mentioned in the handbook entry.

Two themes emerged from the data: engineering for sustainable development and sustainable development, safety, and engineering. Engineering for sustainable development was seen in 10 subjects (30%), with phrases such as "sustainable production of… biochemicals" (CHEN90039). This theme highlighted that the contribution chemical engineering makes to sustainable development is being taught in the curriculum, in addition to basic sustainable development concepts. Four subjects (12%) showed the connection between sustainable development, safety, and engineering. Phrases at this intersection of concepts, such as "operate safely, sustainably and economically" (CHEN90013), show the future of chemical engineering and how sustainable development can be integrated into chemical engineering subjects, as safety is now. The handbook entry for the degree itself also mentions the themes of sustainable development, safety, and engineering. These handbook themes imply that this intersection is important to the overall degree ethos.

While there is alignment between the ethos of the degree and several of its subjects, the same may not be claimed for the alignment between sustainable development and the degree in general. The presence of sustainable development keywords in the degree handbook entry implies that sustainable development is important. But with less than 50% of the subjects having evidence of addressing the topic, there appears to be a misalignment between the goals of the degree and their translation to individual subjects.

While the heat map is only the beginning of assessing the presence of sustainable development in the curriculum, it is a valuable step. The mapping method and resulting heat map can be used to prove the presence of sustainable development or other concepts for accreditation by bodies such as Engineers Australia or discipline-specific bodies such as the Institute of Chemical Engineers. This paper uses chemical engineering as a case study, but the mapping method can be applied to any engineering discipline.

Lessons from handbook entry 'good practice' can be drawn from this case study. Several entries effectively communicate the presence of sustainable development in their curriculum and should be emulated. As with the mapping method, these best handbook entry best practices apply to all engineering disciplines.

- Explicitly discuss which aspects of sustainable development are covered by the subject to provide strong evidence that the concepts are addressed (CHEN90020)
    - e.g., sustainable design, triple bottom line
- Including sustainable development keywords and concepts in multiple sections of the handbook to indicate the concepts are addressed throughout the subjects' curriculum (CHEN30015)
- Including lists of applications and industries for the principles developed in the subject to communicate how this learning is reflected in engineering practice (CHEN20012)
    - e.g., food processing, pharmaceutical manufacturing

Conclusion

The novel method proposed by this paper allowed educators from all engineering disciplines to map the presence of sustainable development in the engineering curriculum quickly and visually. This mapping method is significant as it provides educators with a tool to map degrees and improve student education outcomes. The simple mapping establishes a baseline for sustainable development in the curriculum and highlights opportunities for future improvements. The analysis also provides information on a degree's themes and how they align with its aims.

The case study on the MoCE showed that sustainable development is present throughout most of the chemical engineering curriculum. Still, the degree’s third semester has a sustainable development gap. Despite the limitations of the process, the heat map output provides a foundation for assessing the presence of sustainable development and highlights areas for future improvement. This foundation can be built upon by more detailed mapping studies.

While this mapping technique provides a foundation for integrating sustainable development into the curriculum, a more detailed assessment is required for evidence-based decision-making. This foundational map can be expanded with data such as interviews of teaching materials. The holistic nature of Education for Sustainable Development can also be considered, mapping ESD competencies or the contributions to the SDGs.

Sustainable development in the engineering curriculum is growing more important by the day: this is reflected in current and probable future accreditation requirements. It is essential to start thinking about how sustainable development fits into engineering education sooner rather than later to ensure our engineering degrees shape future engineers. Ultimately, the method and the map produced contribute to improving educational outcomes for engineering students. This, in turn, contributes to improving outcomes for the sustainable development issues our engineering graduates will help solve all over the world.

References

Brundtland, G. H. (1987). *Our common future.* (UniM Archit 363.7 OUR). Oxford University Press; UNIVERSITY OF MELBOURNE’s Catalogue. https://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=cat00006a&AN=melb.b1510135&site=eds-live&scope=site&custid=s2775460

Enelund, M., Knutson Wedel, M., Lundqvist, U., & Malmqvist, J. (2013). Integration of education for sustainable development in the mechanical engineering curriculum. *Australasian Journal of Engineering Education*, *19*(1). https://doi.org/10.7158/D12-018.2013.19.1

Galofré, V. G., & Segalas, J. (2021). Assessing SDGs’ Learning Objectives in Engineering Education. Case Study. Engineering in Industrial Design and Product Development at UPC Barcelona Tech. *2021 SEFI Conference Proceedings*, 9.

Gómez-Martín, M. E., Gimenez-Carbo, E., Andrés-Doménech, I., & Pellicer, E. (2021). Boosting the sustainable development goals in a civil engineering bachelor degree program. *International Journal of Sustainability in Higher Education*, *22*(8), 125–145. https://doi.org/10.1108/IJSHE-02-2021-0065

IEA. (2021). *International Engineering Alliance: Graduate Attribute & Professional Competencies*. International Engineering Alliance. https://www.ieagreements.org/assets/Uploads/IEA-Graduate-Attributes-and-Professional-Competencies-2021.1-Sept-2021.pdf

Lamere, M., Brodie, L., Nyamapfene, A., & Fogg-Rogers, L. (2021). *Mapping and Enhancing Sustainability Literacy and Competencies within an Undergraduate Engineering Curriculum*. 9.

Rajabifard, A., Kahalimoghadam, M., Lumantarna, E., Herath, N., Hui, F. K. P., & Assarkhaniki, Z. (2021). Applying SDGs as a systematic approach for incorporating sustainability in higher education. *International Journal of Sustainability in Higher Education*, *ahead-of-print*(ahead-of-print). https://doi.org/10.1108/IJSHE-10-2020-0418

Rieckmann, M. (2017). *Education for Sustainable Development Goals: Learning Objectives* (p. 68). United Nations Educational, Scientific and Cultural Organization.

Sánchez-Carracedo, F., Moreno-Pino, F. M., Sureda, B., Antúnez, M., & Gütierrez, I. (2019). A Methodology to Analyze the Presence of Sustainability in Engineering Curricula. Case of Study: Ten Spanish Engineering Degree Curricula. *Sustainability*, *11*(17), 4553. https://doi.org/10.3390/su11174553

Sánchez-Carracedo, F., Segalas, J., Bueno, G., Busquets, P., Climent, J., Galofré, V. G., Lazzarini, B., Lopez, D., Martín, C., Miñano, R., Cámara, E. S. de, Sureda, B., Tejedor, G., & Vidal, E. (2021). Tools for Embedding and Assessing Sustainable Development Goals in Engineering Education. *Sustainability*, *13*(21), 12154. https://doi.org/10.3390/su132112154

Trad, S. P. (2019). A framework for mapping sustainability within tertiary curriculum. *International Journal of Sustainability in Higher Education*, *20*(2), 288–308. https://doi.org/10.1108/IJSHE-09-2018-0151

Woolschlager, J. (2013). Implementation of Sustainability Concepts in Environmental Engineering Curriculumns. *2013 ASEE Annual Conference & Exposition Proceedings*, 23.701.1-23.701.11. https://doi.org/10.18260/1-2--19715

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