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Connections between Chemical Engineering Principles and Sustainable Development – Engineer Focus Group

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CONTEXT

Preparing future engineers who can address sustainable development challenges is an important aspect of engineering education. Educators and students can use discipline-specific knowledge to articulate how the discipline contributes to sustainable development issues. While frameworks for discipline-specific sustainable development competencies exist for several engineering disciplines, no such framework currently exists for chemical engineering.

PURPOSE

A chemical engineering-specific sustainable development framework would make integrating sustainable development concepts and competencies into curricula more meaningful, coherent, and comprehensive. This work explores the question, "How can sustainable development be integrated into chemical engineering curricula?". In this paper, we produce a novel, preliminary framework of chemical engineering-sustainable development knowledge.

METHODS

In a focus group, three practicing engineers identified connections between chemical engineering principles and sustainable development. Using qualitative analysis, including coding, we analysed the transcript and artefacts produced by the participants.

OUTCOMES

The framework produced considers two principles: safety and systems thinking. It contains 25 connections and 16 sub-connections across five topics, and examples of use.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The framework and connections from this study can be used to integrate sustainable development concepts, skills, and competencies meaningfully into existing curricula or form the foundations for new curricula. Likely consequences are improved educational outcomes for engineering students, better preparing them for the complex world of sustainability. This will lead to better outcomes for the problems graduate engineers will help solve worldwide.

KEYWORDS

Sustainable development, qualitative data analysis, discipline-specific

Introduction

The need for sustainable development surrounds us in evidence such as climate disruption and the Black Summer bushfires, while 2.3 billion people worldwide are still cooking with unsafe fuels (United Nations, 2023). The most often cited definition of sustainable development is Brundtland's (1987) description: "meeting the needs of the current generations without compromising the ability of future generations to meet their own needs". The current generation is not meeting its own needs, and future generations' ability to meet their own needs is being diminished.

Engineers are uniquely placed to address sustainable development challenges: we exist at the intersection of STEM disciplines and are trained to solve complex challenges. Engineers have a two-fold responsibility. Firstly, many sustainability challenges have arisen from engineering choices, from anthropogenic climate disruption to water pollution: engineers have benefitted from these choices and therefore have a responsibility to remediate the resulting damage. Secondly, engineers are highly trusted professionals working for the benefit of the wider community (Engineers Australia, 2022; IChemE, n.d.). Engineers Australia specifically identifies sustainability as a responsibility in its Code of Ethics: "As engineering practitioners, we use our knowledge and skills for the benefit of the community to create engineering solutions for a sustainable future" (Engineers Australia, 2022, p. 2).

This responsibility of engineers extends to engineering educators and our responsibility to prepare future engineers for sustainable development. Discipline-specific knowledge is an important aspect of this preparation; it provides context for learners and articulates how a discipline contributes to solving sustainable development challenges. Extensive collaboration and co-creation are required to effectively manage and solve sustainability issues, and discipline-specific knowledge enables this collaboration.

A framework of discipline-specific sustainable development knowledge, competencies and capabilities would allow educators to integrate sustainable development into existing curricula meaningfully. By integrating these concepts based on existing content, sustainable development can be added to subjects without additional teaching time. Because all IChemE-accredited chemical engineering degrees teach a similar set of chemical engineering (ChE) principles, basing such a framework on these principles makes the framework accessible to all chemical engineering educators.

Mechanical (Enelund et al., 2013) and civil/ environmental (ASCE, 2019) engineering have frameworks of discipline-specific sustainable development knowledge. However, the comparatively smaller discipline of chemical engineering does not currently have such a framework. A framework in chemical engineering would provide an overdue practical resource to chemical engineering educators.

This research project, outlined in Figure 1, addressed the question, "How can sustainable development be integrated into chemical engineering curricula?". To answer this overarching question, we conducted two focus groups and ran a Delphi survey to explore the connections between chemical engineering principles and sustainable development. In this paper, we discuss the focus group conducted with three practicing chemical engineers.

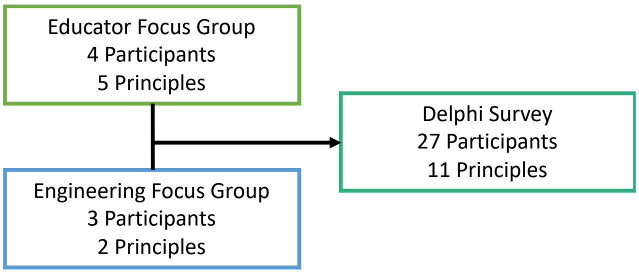

Figure 1: Research Project, including 2 Focus Groups and 1 Delphi Survey

Method

Data Collection

The first author is a Graduate Researcher (GR) facilitated a focus group that allowed participants to discuss the connections between chemical engineering principles and sustainable development. A focus group allowed data collection from multiple participants simultaneously and interaction between participants. The focus group was held online over the meeting software Zoom and used the digital whiteboard software Miro (*Miro*, 2022) (Figure 2).

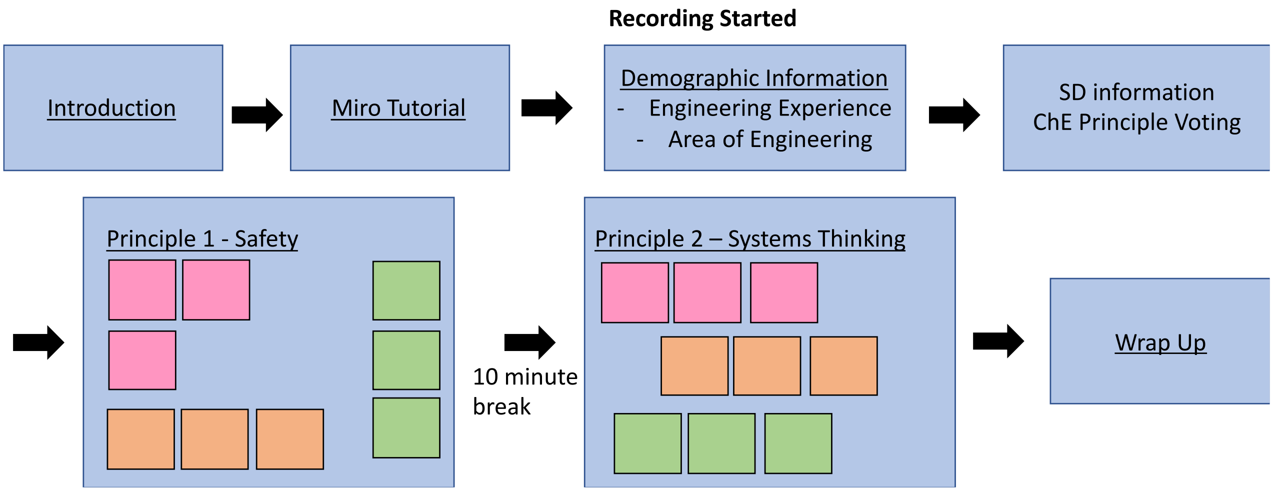

Figure 1: Layout of Focus Group Miro Board

Participants were recruited through our professional networks. All participants had experience with sustainability within the context of chemical engineering practice. Three practicing engineers participated in the study, one each from the regulation, operation, and consulting/ design fields. The GR facilitated the 90-minute focus group using a pre-made digital Miro whiteboard that was also designed by the GR (Figure 2). From the list of principles in Table 1 below, participants voted to discuss “safety” and “systems thinking”

Table 1: List of Chemical Engineering Principles Presented in Focus Group (bolded principles were selected to discuss)

• Control	• Fluid Mechanics	• Gases and Vapours	• Material and Energy Balances
• Reaction Engineering	• **Safety**	• Separation Processes	• **Systems Thinking**
• Thermodynamics	• Transport Processes	• Unit Operations	

To explore the connections between chemical engineering principles and sustainable development, participants were asked, “How does this principle relate to sustainable development?”. Participants were invited to use digital sticky notes on the board and verbally discuss their thoughts. Participants spent approximately 25 minutes on each principle, and there was insufficient time to discuss a third principle, so the focus group ended after discussing the second principle.

The GR transcribed the audio recording of the focus group and the artefacts produced by the participants.

Data Analysis

Qualitative analysis, including coding, was used to analyse the data and transform the collected data into a preliminary framework of connections between chemical engineering principles and sustainable development. Figure 3 below shows the stages of the data analysis process.

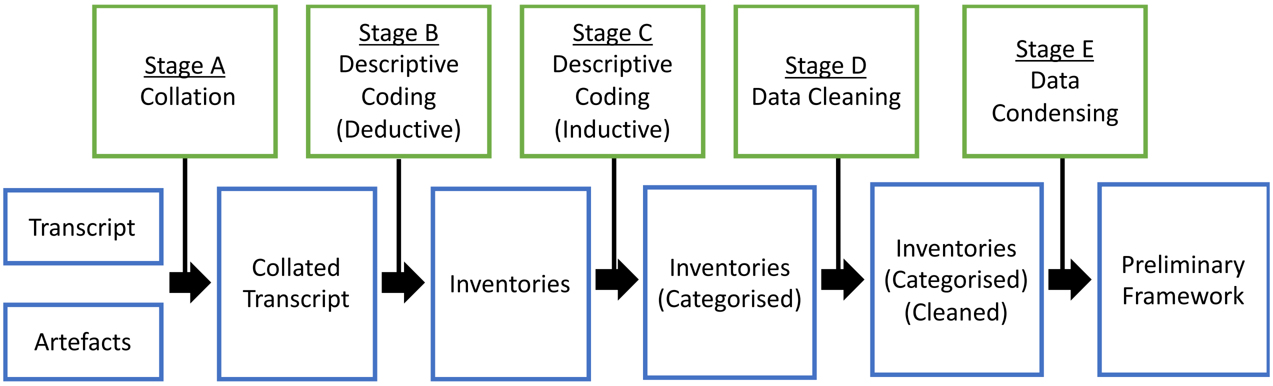

Figure 2: Stages of Data Analysis

Stage A: Data Collation

The GR collated the data collected from the focus groups into a single source for analysis. The written material from the digital sticky notes produced by the participants was added to the audio transcript.

Stage B: Descriptive Deductive Coding

Descriptive Coding was employed and seeks to “summarize in a word or short phrase – most often a noun – the topic of a passage of qualitative data” (Saldaña, 2021, p. 102). Descriptive deductive coding applied pre-determined codes to the data, in this case, the collated transcript. Here, the chemical engineering principles were used as codes. The connections were coded to the principles the participants discussed at the time, such as systems thinking. The output for Stage B was an inventory of connections for both principles discussed in the focus group: safety and systems thinking (Tables 2, 3).

Stage C: Descriptive Inductive Coding

Descriptive inductive coding identifies the codes to apply to the data as the data is being analysed. In this case, topics that describe the connections, such as process design, were applied to the connections.

The output for Stage C was an inventory of connections for both principles discussed by the participants, now categorised by topic. Organising the inventories by topic makes the framework easier to use; similar ideas are grouped, and educators can more easily identify issues relevant to assignments, case studies etc.

Stage D: Data Cleaning

The categorised inventory needed to be cleaned before the content was appropriate for a framework of chemical engineering connections to sustainable development. The data cleaning stage involves removing duplicates and inappropriate connections. Connections were discussed by participants multiple times and thus appeared in the Stage C output multiple times. This duplication was unnecessary for the final framework; thus, duplicates were removed.

Other connections mentioned by participants were relevant to their practice as engineers but were not appropriate for inclusion in a chemical engineering-specific framework of sustainable development knowledge. An exclusion criterion was applied to all connections: "Does this connection apply to chemical engineering as a whole?". Further discussion of the data cleaning in Stage D can be found in Section 3.3 below. Three connections were removed from the framework during this cleaning. The output for Stage D was a pair of inventories, categorised by topic, now containing only relevant data.

Stage E: Data Condensing

The final stage of data analysis involved condensing the data in the inventories into key ideas and examples/ applications of those key ideas (Miles *et al*., 2014). The key ideas were considered connections, and the applications/ examples of those key ideas were considered sub-connections. This stage was performed iteratively with Stage D to ensure the most relevant data was included and properly sorted. This condensing of data into connections and sub-connections allows educators to easily identify the key ideas relevant to their teaching while offering examples of how they are applied in chemical engineering practice.

Stage E's output is a foundational framework of chemical engineering– sustainable development knowledge.

Findings and Discussion

Framework

The data collection and analysis process produced a preliminary framework of chemical engineering – sustainable development knowledge. This framework contained inventories for two principles (safety and systems thinking), five topics, 25 unique connections and 16 sub-connections. Three connections are included in both inventories.

Table 2: Inventory of Safety – Sustainable Development Connections

Topic	Connection to SD	Sub-Connections
Abstract Applications	Expanding HAZOPs to include environmental, social, and economic risk	
	Applying safety principles to sustainability	
Complexity	Managing competing needs	Waste hierarchy Safety hierarchy Environmental impact hierarchy
Process Design	Waste treatment	Minimising waste outputs Waste profile for treatment
	Designing for resilience	
	Simplifying design	

Topic	Connections to SD	Sub-Connection
Regulations/ Governance	Creating appropriate corporate and legislative policy on sustainability	Optimisation policy Safety policy Cost policy
	Managing community expectations	
	Dangerous Goods Management	

Table 3: Inventory of Systems Thinking – Sustainable Development Connections

Topic	Connection to SD	Sub-Connections
Abstract Applications	Applying hierarchy of control to sustainability	Over life of plant Over plant operations
	Applying systems thinking to transport and logistics	Reducing impact of logistics transport Reducing impact on people/ community
Complexity	Managing competing needs	Safety vs. sustainability vs. resources vs. energy
	Allowing for ambiguity	
Process Design	Process optimisation	Recycle loops/ reusing streams Using side/ by-products Ethical sourcing of resources/ inputs
	Designing for resilience	
	Designing for decommissioning	
	Circularity	
	Safety in design	Hazard studies (HAZID/ HAZOP) Safety methodologies Safe operating envelopes Intrinsic safety/ layers of protection
	Design standards	
	Embedding sustainability metrics into front-end design	UN SDGs Lifetime emissions Lifetime energy intensity
Regulation/ Governance	Creating appropriate corporate and legislative sustainability policy	
	Culture of sustainability throughout company	
Misc.	Circularity	Cultural buy-in from management Public perceptions of circularity
	Waste hierarchy	
	Community education programs	
	Framework to measure value and sustainability performance	
	Procedures to account for humans and their performance	

The framework, shown in Tables 2, 3, demonstrates connections between the chemical engineering principles of safety and systems thinking, and sustainable development. This framework, and the connections within it, are important. They demonstrate that sustainable development can be meaningfully integrated into chemical engineering curricula. The framework benefits educators who know sustainable development is an important aspect of engineering education but are still determining where or how to start integrating sustainable development into their teaching.

This framework is not designed to be exhaustive; it covers only two principles and is based on a discussion with three engineers. Instead, this framework explored the types of connections possible between sustainable development and chemical engineering principles. As outlined in Figure 1, this study was designed to prepare for the Delphi survey (in progress).

Framework Implementation

The framework produced in this study is preliminary but can still be used to integrate sustainable development into existing chemical engineering curricula. Many chemical engineering subjects teach both safety and systems thinking. These subjects, therefore, have an opportunity to introduce sustainable development into curricula.

For example, foundational chemical engineering safety subjects often introduce the HAZOPS (HAZard and OPerability Studies) process. When discussing the impacts of the safety incidents at the centre of the HAZOPS, educators can encourage the students to discuss the impact on the community and local environment, in addition to the traditional economic and chemical plant impacts.

Exclusion Criteria

Not all connections discussed by the participants were appropriate for a framework of chemical engineering – sustainable development knowledge designed for Entry to Practice degrees. Several connections related closely to the professional fields of two participants: industrial waste processing and emergency management. Therefore, an exclusion criterion was applied to all connections to ensure that only appropriate connections populated the final framework.

The exclusion criterion was “Does this connection apply to chemical engineering as a whole?”. If the connection could apply to most/ all the fields of chemical engineering, then the connection was included. If the connection only applied to one industry, it was considered too niche for the framework and excluded, as seen in Table 4.

Table 4: Examples of Exclusion Criteria

Category	Definition	Example	Included/ Excluded from framework
Niche	Connection applies only to a specific industry e.g., waste management	“Appropriate resources in place [for emergency management]”	Excluded
General	Connection applies to chemical engineering as a whole	Managing competing needs and hierarchies	Included

Three connections were removed through this exclusion criterion, leaving 25 unique connections. It is important to note that the excluded connections are still valuable in demonstrating the role of chemical engineering practice in sustainable development. However, these connections are better suited for continuing professional development in specific industries rather than a framework for entry-to-practice chemical engineering students.

Dimensions of Sustainable Development

While the framework is not exhaustive, it represents a holistic model of sustainable development in chemical engineering practice. All three pillars of sustainable development (environmental, socio-cultural, economic) are present in the framework, with examples in Table 4. The holistic nature of SD is also included with connections such as "expanding HAZOPs to include environmental, social, and economic risk". The UN Sustainable Development Goals (SDGs) are also present in the framework.

This holistic representation of SD in this framework provides a holistic foundation for the larger framework currently being developed throughout the overarching study. For the framework to be most effective for our students, it must model a holistic view of sustainable development.

Table 4: Examples of Sustainable Development Pillars and Framework Connections

SD Dimension	Example Connection to SD Dimension
Environmental	Managing competing needs (environmental impact)
Socio-cultural	Expanding HAZOPs to include environmental, social, and economic risk
Economic	Plant's lifetime energy use

Limitations

The first limitation is that the participants discussed only two out of a possible 11 principles. However, these two principles were discussed more deeply than if participants discussed four or five principles. Additionally, this research aimed to explore the types of connections possible between chemical engineering principles and sustainable development. Therefore, exploring these principles deeply, rather than widely, is more appropriate for this study.

An educator focus group preceded this engineer focus group (Bury *et al*., 2023): both focus groups explored the connections between ChE principles and SD but explored different topics with different participants. The results from both focus groups also contributed to the Delphi study that is currently running (Figure 1). These additional studies in the research project overcome many limitations of this small engineer focus group.

Conclusions

This paper produced a foundational framework of chemical engineering – sustainable development knowledge through a focus group with practicing chemical engineers, using qualitative data analysis, including coding.

This framework contains 25 unique chemical engineering-sustainable development connections, 16 sub-connections and five topics across two chemical engineering principles. This framework allows educators to integrate sustainable development into their subjects meaningfully. This focus group method can also be used in other engineering disciplines to create a framework of discipline-specific sustainable development knowledge.

Meaningfully integrating sustainable development into the chemical engineering curriculum can lead to better educational outcomes for our engineering students. And it will ultimately lead to the future generation of engineers being better equipped to solve the global challenges of sustainable development.

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