Correlation Between Engineering Students' Perceptions of Sustainability and Their Understanding of the Threshold Concepts in Their Disciplines

Sina Enteshari[a]; Wendy Fox-Turnbull[b], Jonathan Scott[b], Sally Male[c].
Wintec[a], University of Waikato[a,b], University of Melbourne[c]
Corresponding Author Email: sina.enteshari@wintec.ac.nz

ABSTRACT

CONTEXT

Sustainability is an important concept in engineering education. Although it is not a new idea in engineering education, its implementation presents a number of obstacles. To support curriculum development, we looked into the fundamental and transformative learning in sustainability, known as 'threshold concepts'. A series of concepts that has the ability to transform the way students perceive sustainability in their disciplines. In this study, we attempt to answer the question, how do engineering students perceive and understand sustainability within the context of their discipline's core concepts?

PURPOSE OR GOAL

Using threshold concept theory, we investigated how students in various engineering disciplines perceive sustainability and identified what they thought to be the crucial sustainability principle in their disciplines. We hoped to improve sustainability engineering education initiatives and promote the incorporation of sustainability concepts into various engineering disciplines' curricula by changing students' and educators' perceptions of sustainability.

APPROACH OR METHODOLOGY/METHODS

The study used a mixed-methods approach, which included both quantitative and qualitative data collection techniques. A structured survey was distributed to students from a variety of disciplines, including civil, software, electronics, mechanical, chemical, and material processing engineering. In addition to the survey, qualitative data were gathered through interviews with a subset of these students, allowing for a more in-depth exploration of individual perspectives. The analysis also included a review of first-year engineering students' reflective essays and reports, which provided additional qualitative insights into their perspectives on sustainability.

OUTCOMES

Our research found that the content of sustainability courses significantly shapes students' overall understanding of sustainability and its relevance to their specific discipline. A key hurdle in integrating sustainability into engineering education is its perceived irrelevance. Students favoured content that's tailored to their discipline, aligning with their existing discipline specific threshold concepts. For instance, software engineering students felt that general sustainability courses didn't apply to them, preferring courses that incorporate sustainability in a way that's directly relevant to them. They aimed to gain knowledge that would complement and expand upon their prior studies.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Our study revealed that sustainability-related threshold concepts are distinct for each discipline, highlighting the need for customised approaches to foster engagement and understanding. These insights can help educators craft teaching strategies that enhance students' grasp of these concepts and promote the application of sustainable practices within their disciplines. A major difficulty in integrating sustainability into engineering education was the lack of discipline-specific

content, leading many students to overlook sustainability concepts that didn't directly relate to their studies.

KEYWORDS

Sustainability, Engineering Education, Perception, Attitude, Pedagogy, Threshold Concept Theory.

Introduction

Engineers are key players in socio-economic progress, facing the challenge of addressing global sustainability issues through their work in technology, science, and mathematics. They design, develop, and innovate using materials, machines, tools, and systems (Marjoram et al., 2010). engineers bridge the gap between science and real-world applications as creators and innovators . That is why they are holding significant influence in promoting sustainable practices worldwide (Marjoram et al., 2010; Striebig, B. A., Ogundpie, A. A., Papadakis, 2014).

Sustainability education fosters skills to understand the impacts of engineering on the environment, society, and economy (Rosano, 2018), involving the resolution of current problems without depleting future resources. This approach aims to shift engineers' thinking on technological, managerial, and moral levels for positive societal, environmental, and economic outcomes (Cristina, 2016; Rosano, 2018). However, teaching sustainability in engineering is complicated, leading to a lack of balance between environmental, social, and economic aspects (Olawumi & Chan, 2018; Rampasso et al., 2018).

Although sustainability is widely accepted, it is often criticised for being unclear and not leading to major changes, especially in addressing ecological issues and shifting the focus from economic growth to human well-being and justice (Loringa, 2020). A robust model is essential to effectively integrate sustainability into engineering education.

The existing definition of sustainability contains shortcomings that must be addressed in educational curricula. Incorporating threshold concepts could help clarify and build a common understanding of sustainability education. Consequently, it is crucial to develop innovative methods to engage engineering students in exploring the foundational aspects of sustainability and threshold concepts in sustainable engineering (Enteshari, 2023).

Theoretical framework: Threshold concepts

A 'Threshold Concept' in academic disciplines refers to a key idea that, once understood, fundamentally changes how a student views the subject (Scott & Harlow, 2012). Threshold concepts differ from core concepts based on five key characteristics identified by Meyer & Land (2003):

- Transformative: Once understood, they lead to a fundamental shift in the learner's understanding of the subject matter.
- Irreversible: Once grasped, these concepts cannot be unlearned.
- Integrative: They reveal previously unseen connections between different concepts.
- Bounded: They are specific to a particular discipline.
- Troublesome: They are inherently difficult for students to understand.

Threshold Concepts (TC) lead to significant changes in a student's thinking and understanding, marking their transition from novice to expert. As Scott et al. (2010) mentioned, this shift is more about ontological changes than epistemological ones. However as Male & Bennett (2015) points out the epistemological shift has equal important to helping students grasp TC in their disciplines.

Previous studies in engineering education have primarily focused on technical concepts, such as foundational electronics (Male & Bennett, 2015; Scott & Harlow, 2012) nd advanced electrical engineering topics beyond the first year (Flanagan et al., 2010). These concepts serve as key TC that shape how students begin to think and understand like engineers(Male & Bennett, 2015).

This deep transformation helps students become part of their disciplines, enabling them to perceive their world differently and understand the concepts within it. In other words, it's about how they start thinking like an engineer. This shows that students' perception of their discipline greatly influences their grasp of Threshold Concepts, particularly when they are in the liminal stage and are still imitating their learning (Enteshari, 2023).

The liminal stage, often characterised by uncertainty and mimicry, signifies that students are still grappling with the foundational concepts of sustainability in their discipline. The state of liminality involves a transition from one state of understanding to another, often requiring students to move through a metaphorical "dark tunnel" where concepts are initially ambiguous and challenging to grasp (Scott & Harlow, 2012).

As students navigate this tunnel, their understanding evolves, but until they fully internalise these concepts, their interpretations remain incomplete and potentially flawed. This indicates that a thorough analysis of how students perceive sustainability at this stage can provide insights into the barriers they face and the support they need to achieve a deeper, more integrated understanding of sustainability within their engineering discipline (Enteshari, 2023).

Engineering Students' Perception of Sustainability

Students need intrinsic motivation to engage in sustainability initiatives, as it drives their studies. McCormick et al. (2015) emphasize that learning requires cognitive growth support. Higher education is crucial for instilling sustainable ideals and abilities, benefiting societal advancement (Mulder, 2017; Rosano, 2018). Wilson (2019) notes engineering students feel responsible for addressing sustainability, but it needs to be integrated in their disciplines. Identifying students' perceived responsibilities bridges disciplines and sustainability. Curriculum design affects students' focus on sustainability aspects. A comprehensive, interdisciplinary approach to education is needed, as students may perceive sustainability as disconnected from their specific fields (Wilson et al., 2015).

Engineering students' perceptions of sustainability vary across disciplines, which greatly influences their level of engagement with the subject. Studies, such as those by Wilson et al. (2015), show that many students regard sustainability as an abstract, ill-defined concept, often disconnected from their technical disciplines. This perception results in a reluctance to integrate sustainability into their discipline and future professional practices.

Furthermore, students' exposure to sustainability concepts is frequently fragmented, with a strong emphasis on environmental aspects over social and economic dimensions, as highlighted by Aginako & Guraya (2021). This imbalance leads to a narrow understanding of sustainability, confined to specific environmental concerns rather than a holistic view encompassing all pillars of sustainable development (Enteshari, 2023).

Students' perceptions of sustainability are influenced by factors such as prior knowledge, cultural background, and learning context. Additionally, the context in which students learn greatly impacts their understanding, with meaningful experiences and discipline-specific content enhancing comprehension of sustainability in their disciplines (Enteshari, 2023).

Methodology

This study recognizes that students' perceptions of sustainability are impacted by their own experiences from disciplinary backgrounds and educational contexts. Understanding these views needs an exploration of the subjective worlds generated by students themselves.

This research adopts an interpretivist paradigm, claiming that human social and physical experiences are interpretive and cultural (Neuman, 2011). Various realities exist, and the context of these realities can provide a explanation for an individual's perspective. Considering these aspects and their lived experiences, each participant's viewpoint is seen as potentially unique (Creswell & Plano Clark, 2017). Each participant gives meaning in their own way, resulting in the creation of numerous worlds.

Even when two people are in the same circumstances, their perspectives are recognised as different. This research aimed to illuminate each participant's created world. Our epistemological stance is that knowledge is not 'discovered' but created through the knower's experience (Lincoln & Guba, 2013). Meaning can be generated in various ways, even regarding the same concept. Thus, multiple conflicting but equally valid explanations of the same concept are possible within constructionist epistemology (Gray, 2017). Given that this research focuses on students who create meaning in different ways and backgrounds, constructionist epistemology was deemed most suitable.

This study explored students' perception and their understanding of sustainability. Epistemologically, the research, built knowledge by examining each participant's experiences and perspectives. This study aimed not only to understand participants' views and experiences but also to highlight threshold concepts across different disciplines. This method was seen as closely related to a phenomenographic approach, which aims to "characterize variation in people's experiences" (Richardson, 1999, p. 64), instead of looking at individual experiences, phenomenography helps us understand all participants' different views on sustainability as a whole.

Methods

Threshold concept theory serves as the theoretical framework for this study. Consequently, the methods used were aligned with the recommended tools necessary for researchers to identify threshold concepts in any discipline. In the context of sustainability education, identifying threshold concepts could help educators design curricula that effectively foster deep, meaningful learning. The research follows a mixed-methods design, combining qualitative and quantitative approaches to gain a comprehensive understanding of sustainability threshold concepts in engineering education.

This study is based on Crotty's (1998) model, which covers different levels of decision-making in research design. Data collection and analysis are carried out using a variety of approaches, including questionnaires, interviews, focus groups, and document analysis. This triangulation enhances the validity and reliability of the findings.

The questionnaires included both closed and open-ended questions to capture a wide range of data. The quantitative data were analysed using descriptive statistics to summarise the data and provide initial insights into students' perceptions of sustainability. The questions covered themes such as the importance of sustainability in personal and professional contexts, understanding of the triple bottom line (environmental, social, and economic dimensions), and discipline-specific relevance.

Semi-structured interviews and focus groups were conducted to collect qualitative data from a smaller, more focused sample of students and lecturers. These methods allow for in-depth exploration of perspectives and experiences of participants, providing rich, detailed data that complemented the findings from the questionnaires.

The qualitative data from the interviews and focus groups were analysed using NVivo software. Thematic analysis was used to identify and categorize the key themes and patterns that emerged from the data. This involved an iterative process of coding and recoding the data, constantly refining the categories and themes until a clear and coherent picture of the participants' perspectives and experiences was obtained.

Document analysis was used to supplement the primary data collected. Secondary data, such as student assignments and course materials, were analysed to provide additional insights into the teaching and learning of sustainability in engineering education. The data from the document analysis were analysed using content analysis, which involves systematically coding and categorizing the content to identify key themes and patterns.

In summary, the chosen methodology provided a comprehensive foundation for exploring the key research objectives. With this methodological framework in place, the next section presents the findings that emerge from this approach, highlighting the connections between sustainability education and threshold concept theory.

Results

This section presents the key findings derived from the data analysis, addressing the research objectives outlined earlier. Our study explored engineering students' perceptions of sustainability across multiple disciplines, with a focus on their professional and educational experiences. This study found that the personal perception of student is heavily influenced by their perception of sustainability in their disciplines.

The concept of sustainability was interpreted differently by each participant, based on their unique experiences in their discipline. "From my perspective, sustainability should be the way that one, particularly an engineer, tries to save the environment as quickly as possible," a civil engineering student said. Civil engineering students were primarily concerned with environmental sustainability. They emphasise the value of recycling and reusing resources in infrastructure projects, such as employing recycled asphalt for road construction or putting recycled concrete into new buildings. This strategy is seen as critical for reducing environmental deterioration and increasing the longevity of materials.

"I'd like to add that sustainability primarily focuses on the environment. Damaging the environment is detrimental since everything depends on it. As long as the environment is here, it's crucial for us to sustain it (Material processing student)."

Similar to civil engineering students, participants in material and processing disciplines viewed sustainability through the lenses of environmental conservation and effective resource use. They promote pollution-reducing techniques and the preservation of resources for future generations. “I think the key point as engineers….resources should be enough for our future generations” said one of the participants. This perspective is integrated into their understanding of engineering techniques, emphasising the importance of long-term solutions in manufacturing and production processes.

Electronics and electrical engineering students prioritise the design of sustainable products, with an emphasis on lowering the need for repairs and extending product life. Although they acknowledged environmental concerns, they believed that the environment is not the primary concern; rather, it is considered an afterthought within a system thinking perspective.

"Some of the most sustainable electronic design can be achieved by simply improving the design itself. If we aim to be sustainable, we need to start developing better designs... However, learning about the environment as an electronics and electrical engineer doesn’t offer a huge financial gain for us; it’s more of a consideration among many others (electronics and electrical student)."

Software engineers' perceptions of sustainability in their discipline were different from the rest, but not unrecognisable. They didn't consider sustainability to be as critical to their field as it is to other disciplines and struggled to connect with it. “What exactly does software sustainability entail? Just where does it belong, exactly? To this day, it remains on the level of vagueness, “commented one of software engineer participants. Software and electrical engineer students view sustainability primarily through economic and social lens, focusing on efficient and smart design of their products.

“….From software engineering perspective….the impact software has on society is tremendous, like with social media influencing elections. People don’t realize the social implications of software because they don’t understand software engineering. To solve this, we need consensus and co-design, ensuring solutions are economically viable, as economics drives everything (Software engineering lecturer).”

Software engineers found it difficult to integrate sustainability into their technical studies because they saw it as separate from their main technical focus. They stressed the importance of teaching sustainability using concepts that are directly relevant to their field. Their understanding of sustainability in software engineering was influenced by a course focused on advanced software methodologies. One student reflected, “I did a paper on software methodology, and it is probably more along the sustainability line for software than this [current sustainability course]" This course emphasized the efficiency of software throughout its lifecycle, from development to usage and disposal, preparing students for what they will encounter in the future.

Students' perceptions of sustainability varied across different disciplines, with each field emphasising concepts most relevant to its area of study. In essence, each discipline prioritized aspects of sustainability that aligned with what they deemed important, based on the collective experience gained from their specific academic focus. This highlights the diverse focus within each discipline, where environmental or economic aspects are prioritized based on relevance to their field of study, supporting the notion that each discipline views sustainability through a lens aligned with their academic and professional goals.

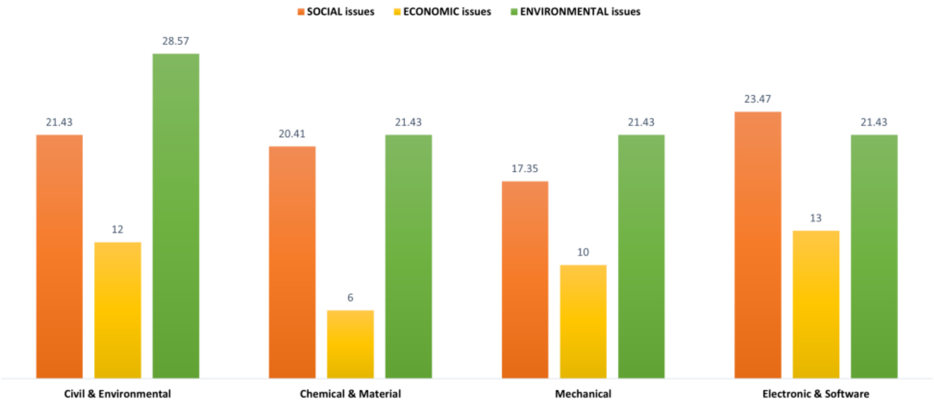

Figure 1: Students' views on the importance of sustainability in their discipline

Most students, regardless of discipline, recognize the importance of the environmental and social pillars of sustainability. However, there is variability in how much emphasis each discipline places on these aspects compared to economic considerations (Figure 1). Students from disciplines like civil, mechanical, and chemical, who are more exposed to environmental science courses, tend to prioritize environmental sustainability more than those in electronics and software (Figure 1).

Many students felt they had little influence over sustainability practices in the industry, as decisions were often made by senior management. This left them feeling disempowered and less motivated to learn about sustainability, creating a sense of hopelessness in their ability to make a difference. One student expressed there was "no hope of contributing to decision-making" on sustainability, which was typically controlled by those in higher positions. Another student noted, "I might eventually reach management and apply these concepts, but those above me have their own perspectives." Economic and operational constraints further impacted this feeling, as students observed that market demand and profitability tend to drive sustainability efforts more than ethical or environmental concerns.

The findings illustrate how engineering students perceive and understand sustainability through the lens of their discipline's core concepts. While majority of disciplines acknowledge the importance of sustainability, their engagement with it varies depending on how closely it aligns with the technical frameworks and priorities of their field. This variation underscores the discipline-specific challenges in integrating sustainability into core engineering education, setting the stage for further analysis in the following section.

Discussion and Conclusion

The perception of students cannot be fully understood without considering the threshold concepts inherent in each discipline. These concepts shape and define each field, influencing how students comprehend the world and approach sustainability challenges. Their understanding and learning are integrated with their perception of these critical concepts.

The threshold concept signifies a profound shift, not only in cognitive understanding but also in how students approach and apply concepts once they grasp them. This shift becomes evident when comparing the perceptions of first-year students with those of final-year students. First-year students often see sustainability as highly relevant, whereas more advanced students (in their fourth year) tend to view it as less critical compared to other technical competencies. This contrast highlights the transformative nature of threshold concepts. For first-year students, sustainability is seen as an idealistic and broad concept. However, as they progress, the integration of discipline-specific threshold concepts reshapes their understanding, often leading them to perceive sustainability as more disconnected from their core technical focus.

Students did not find sustainability inherently troublesome, but rather frustrating, due to its broad and multifaceted nature. In the context of threshold concepts, the "troublesome" aspect is crucial, as it typically signals deeper learning and transformation. While the transformation in students' understanding of sustainability from first to fourth year has already been observed, pinpointing the exact troublesome aspect of sustainability is more challenging, given its wide scope. However, by analysing how each discipline prioritizes specific sustainability-related concepts, particularly among fourth-year students, we can begin to identify the troublesome aspects that align more closely with their technical focus.

Currently, sustainability education is presented with a holistic, one-size-fits-all approach. This study showed that this method is not optimal for learning sustainability within individual disciplines. The solution can be found within the discipline-specific content. This study found each engineering discipline has its unique threshold concepts related to sustainability, reflecting the specific technical and practical concerns of the field. These discipline-bounded concepts are essential as they not only define the scope of sustainability within each field but also shape how students perceive and apply sustainability principles.

In fields like civil, environmental, and material and processing engineering, sustainability was perceived to be important, and the threshold concept involved comprehending the entire lifecycle of materials and systems. This holistic perspective transforms students' approaches to design and construction, highlighting the importance of minimizing environmental impact and optimizing resource efficiency.

In electronics and software engineering, sustainability is often perceived as less relevant compared to other disciplines. Electronics engineers tend to view sustainability concerns as external to their core technical skills, with environmental considerations frequently overshadowed by economic priorities. While sustainability is acknowledged, it is often seen as a secondary concern rather than integral to their work. Similarly, software engineers struggle with the concept of sustainability, finding it vague and disconnected from their technical focus. Their education typically emphasizes short-term practical and economic outcomes, which makes it difficult for them to see how sustainability aligns with their daily practices. This perceived disconnect between sustainability and their disciplines contributes to a lack of meaningful engagement with sustainability concepts, particularly when compared to fields such as civil or environmental engineering.

For electrical engineers, the threshold concept was focused on automation and system design with an emphasis on reducing environmental impact. The challenge for these students was aligning sustainability principles, such as energy efficiency and Life Cycle Assessment (LCA), with the practical demands of electrical system design. The threshold concepts revolved around energy efficiency and the environmental impact of electronic materials and components. the focus from merely achieving technical performance to balancing functionality with sustainability considerations.

The threshold concept of sustainable software development encompasses designing software with considerations for energy efficiency, long-term maintenance, and minimizing computational resources. Therefore, the threshold concepts can be identified as understanding and application of non-functional requirements in the context of sustainability. Software engineers had to reconceptualize the role of efficiency, resource optimization, and long-term system sustainability as critical, non-functional aspects of their design processes. This shift in thinking marked a key conceptual threshold, as sustainability moved from being an external consideration to an integral part of software development.

Perceptions of sustainability among engineering students are profoundly shaped by discipline-specific threshold concepts. These concepts act as transformative gateways that redefine students' understanding and application of sustainability within their fields. By focusing on these critical concepts, engineering education can be enhanced to produce graduates who are not only technically proficient but also capable of addressing the complex sustainability challenges of the modern world. In fields like civil and environmental engineering, where sustainability is naturally integrated into technical and design practices, students tend to see it as highly relevant. They understand sustainability as directly related to their work on infrastructure, resource management, and environmental impact.

Conversely, in disciplines such as electronics and software engineering, students perceive sustainability as less central to their core competencies. These students often view sustainability as either external or unrelated to their technical focus, particularly when economic and practical concerns dominate their learning experience. As a result, they tend to engage less deeply with sustainability, seeing it as an abstract or secondary concept rather than a transformative aspect of their field.

The findings in this study highlight the importance of addressing each discipline's unique perception of sustainability. Creating an environment where all disciplines feel connected to sustainability is essential for improving students' understanding. This can only be achieved if sustainability is not taught as a one-size-fits-all concept, but instead, is designed to be specific and relevant to each discipline's threshold concepts. By tailoring sustainability education to the core concepts of each field, students are more likely to engage with and integrate sustainability into their professional practices.

Future research should explore how psychological concepts like the "blue mind" (calm) and "red mind" (stress), along with Kahneman's "Thinking, Fast and Slow" model, affect students' engagement with sustainability. This could lead to more effective educational strategies by aligning teaching methods with different cognitive and emotional states.

References

Aginako, Z., & Guraya, T. (2021). Students' Perception about Sustainability in the Engineering School of Bilbao (University of the Basque Country): Insertion Level and Importance. Sustainability, 13(15). https://doi.org/10.3390/su13158673

Creswell, J. W., & Plano Clark, V. L. (2017). Designing and conducting mixed methods research (3rd edition). SAGE.

Cristina, M. D. (2016). Promoting Technological Entrepreneurship through Sustainable Engineering Education. Procedia Technology, 22, 1129–1134. https://doi.org/10.1016/j.protcy.2016.01.159

Crotty, M. (1998). The foundations of social research: Meaning and perspective in the research process. In Sage. St Leonards, NSW : Allen and Unwin.

Enteshari, S. (2023). Identification of Sustainability's Threshold Concept (s) Among Multi-Discipline Engineering Students [Doctoral dissertation]. The University of Waikato.

Flanagan, M. T., Taylor, P., & Meyer, J. H. F. (2010). Compounded Thresholds in Electrical Engineering (R. Land, J. H. F. Meyer, & J. Smith, Eds.). Sense Publishers.

Gray, D. (2017). Doing research in the real word. In SAGE Publications (1st ed., Vol. 4, Issue 3). SAGE Publications.

Lincoln, Y. S., & Guba, E. G. (2013). The Constructivist Credo. In E. G. Guba (Ed.), The Constructivist Credo (1st ed.). Routledge. https://doi.org/10.4324/9781315418810

Loringa, P. A. (2020). Threshold concepts and sustainability: Features of a contested paradigm. Facets, 5(1), 182–199. https://doi.org/10.1139/FACETS-2019-0037

Male, S. A., & Bennett, D. (2015). Threshold concepts in undergraduate engineering: Exploring engineering roles and value of learning. Australasian Journal of Engineering Education, 20(1), 59–69. https://doi.org/10.7158/D14-006.2015.20.1

Marjoram, T., Zhong, Y., Kolmos, A., Du, X., Organizations;, W. F. of E., Sciences;, I. C. of A. of E. and T., Engineers;, I. F. of C., & Bokova, I. (2010). What is Engineering? In I. Bokova (Ed.), Engineering: issues, challenges and opportunities for development; UNESCO report (p. 396). UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000189753?locale=en

McCormick, M., Bielefeldt, A. R., Swan, C. W., & Paterson, K. G. (2015). Assessing students' motivation to engage in sustainable engineering. International Journal of Sustainability in Higher Education, 16(2), 136–154. https://doi.org/10.1108/IJSHE-06-2013-0054

Meyer, J. H. F., & Land, R. (2003). Threshold Concepts and Troublesome Knowledge: Linkages to Ways of Thinking and Practising Within the Disciplines. In Improving Student Learning – Ten Years On. (Vol. 4, Issue 1, pp. 1–16). Citeseer. http://ww2.dkit.ie/content/download/14622/88534/file/Threshold Concepts and Troublesome Knowledge by Professor Ray Land.pdf

Mulder, K. F. (2017). Strategic competences for concrete action towards sustainability: An oxymoron? Engineering education for a sustainable future. Renewable and Sustainable Energy Reviews, 68, 1106–1111. https://doi.org/10.1016/j.rser.2016.03.038

Neuman, W. L. (2011). Social research methods : qualitative and quantitative approaches (7th ed.). Allyn and Bacon.

Olawumi, T. O., & Chan, D. W. M. (2018). A scientometric review of global research on sustainability and sustainable development. Journal of Cleaner Production, 183, 231–250. https://doi.org/10.1016/j.jclepro.2018.02.162

Rampasso, I. S., Anholon, R., Silva, D., Cooper Ordoñez, R. E., Quelhas, O. L. G., Leal Filho, W., & Santa-Eulália, L. A. (2018). An analysis of the difficulties associated to sustainability insertion in engineering education: Examples from HEIs in Brazil. Journal of Cleaner Production, 193, 363–371. https://doi.org/10.1016/j.jclepro.2018.05.079

Richardson, J. T. E. (1999). The concepts and methods of phenomenographic research. Review of Educational Research, 69(1), 53–82. https://doi.org/10.3102/00346543069001053

Rosano, M. (2018). Core Concepts and Challenges in Sustainable Engineering Education in Australia. Australasian Association for Engineering Education., 1. https://s3-us-west-2.amazonaws.com/18aaee/proceedings/AAEE18_Rosano_179.pdf

Scott, J., & Harlow, A. (2012). Identification of threshold concepts involved in early electronics: Some new methods and results. Australasian Journal of Engineering Education, 18(1), 61–68. https://doi.org/10.7158/d11-141.2012.18.1

Scott, J., Harlow, A., & Peter, M. (2010). Threshold Concepts and Introductory Electronics. In AAEE 2010 (pp. 409–416). AAEE. https://hdl.handle.net/10289/4917

Striebig, B. A., Ogundpie, A. A., Papadakis, M. (2014). Engineering Applications in Sustainable Design and Development. Nelson Engineering.

Wilson, D. (2019). Exploring the Intersection between Engineering and Sustainability Education. In Sustainability (Vol. 11, Issue 11). https://doi.org/10.3390/su11113134

Wilson, D., Roberts, R., Allendoerfer, C., & Joo Kim, M. (2015). A Sustainability Toolbox for Engineers: Exploring how Students are likely to Engage in Sustainability Education.

Copyright statement