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Decentring engineering education beyond the technical dimension: ethical skills framework

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Abstract

Engineering plays a key role in society today, influencing social behaviour, economic systems, (un)sustainability and future construction. Faced with this central and powerful role of engineering, it is urgent to recognise the need for professionals in this area to be culturally competent and sociopolitically committed in the collective ethical construction of the common good. Engineering course curricula generally focus on technical-scientific training – as is the case in Portugal – not on including or valuing other educational dimensions (namely, social, ethical, cultural or political responsibility). However, to promote an ethically responsible and sustainable future, it is imperative that these dimensions are included in engineers' training, namely through ethical education that promotes a responsible professional practice that contributes to a viable common future.

Intending to contribute to a culturally responsive engineering education, and to the development of the pedagogical dimension of the ethical education of engineering students, this study aims to develop a framework of the ethical skills necessary for the professional practice of engineering. The methodology used included a systematic literature review and document analysis. The developed framework allows systematising and interconnecting ethical skills, which can promote and facilitate the inclusion of ethical education in engineering courses. The framework helped to design a curricular module in engineering. It is a useful tool for professors of ethics in engineering, for those responsible for structuring engineering curriculum plans and for anyone responsible for enhancing this field of engineering education.

Keywords ethical education; engineering; framework; ethical skills; culturally responsive engineering education

Background

Throughout history, engineering has played a central role in the evolution of humanity, in its relationship with the environment, in the distribution of wealth and in sustaining power (Franklin, 2017; Noble, 1977; Riley and Lambrinidou, 2015; Wisnioski, 2015). Importantly, the technology developed through engineering expands the capacity of industrial production, which requires excessive consumption of energy and natural resources for the production process. Industrial production also requires the high extraction and processing of natural resources, which are also made possible by the technology developed through engineering, which expands the capacity of human action. In post-consumption – despite very few exceptions – the goods produced end up being discarded and converted into waste, that is, into environmental pollution. This leads to the accelerated overexploitation of natural resources, as well as their excessive consumption, and it does not allow for the natural replacement of resources (if renewable), leading even to the exhaustion of non-renewable natural resources. This continuous and ever-increasing overexploitation leads in turn to the alteration and degradation of the environment, causing the devastation of ecosystems and the rise in pollution. The central role that engineering played in the past, as well as in contemporary times, and the current environmental unsustainability show how engineering also strongly conditions the construction of possible futures (Monteiro et al., 2019). However, engineers are unaware of the power of engineering and its possible consequences (Lawlor, 2013; Rego and Braga, 2014), partly because these topics are not usually included in the training of engineers (Monteiro and Sousa, 2022a). In the past, these topics were not covered in engineering courses because engineering was considered to be neutral from a political and ethical point of view (Dürr, 1999). Ethical neutrality is based on the assumption that engineering only develops technology that is requested and used by third parties. Therefore, engineering was not responsible for the use of the technology it created, nor for the consequences that resulted from it (Jonas, 2015). This is still the dominant paradigm in engineering education today, and in Portugal more particularly (Monteiro and Sousa, 2022a). However, this perspective does not take into account that technological development is carried out with knowledge of the intended application of the technology, and that technology itself changes people’s behaviour and the functioning of society. Furthermore, the choices made by engineers during the technology development process also affect the future use of this technology, and these choices can change depending on the engineers’ perspectives.

However, given the powerful role of engineering in society today, it is urgent to recognise the need for professionals in this area to be culturally responsive and committed sociopolitically in the collective ethical construction of the common good respecting cultural diversity (Raworth, 2017; Riley and Lambrinidou, 2015). To contribute to a culturally responsive engineering education (Gay, 2000), it is not only necessary for engineers to be trained in a conscious vision of the power of engineering, and for this power to be used responsibly and for the common good (including aspects such as social justice, cultural diversity and sustainability) (Riley and Lambrinidou, 2015); it is also necessary that the engineering profession ‘demonstrates ethical behaviour in its decision making, from the very technical level to the strategic' (Royal Academy of Engineering and Engineering Council, 2022: 2). This implies a change in the dominant paradigm in engineering education (Fromm, 2003).

Decentring from the dominant paradigms in engineering education

The dominant paradigm in engineering education perpetuates a vision centred on the ethical neutrality of engineering (Jonas, 2015; Monteiro and Sousa, 2022a). The main focus of this paradigm is the service that engineering provides to economic growth (Jamison et al., 2014; Kranzberg, 1986), in which technological evolution is seen as a good in itself (Lipovetsky, 2013). This perspective argues that progress becomes unstoppable (Wootton, 2015), and that engineering has a 'superpower' that cannot be stopped, which allows it to make the impossible technically possible (Lipovetsky, 2013).

This perspective circumscribes engineering (subduing it to economics) and keeps its teaching limited to the decontextualised technical-scientific dimension (Jamison et al., 2014). This focused and limited view ignores what goes beyond technical and economic numbers, and therefore tends to ignore the side effects and/or unwanted effects (Raworth, 2017), for example, at the human and environmental level (excluding environmental engineering).

By teaching or studying the technical-scientific dimension uprooted from the reality of its sociocultural–political–economic–environmental application, engineers' disengagement in the face of sociopolitical issues is promoted. But this dimension is necessary for a culturally responsive STEAM (science, technology, engineering, arts and mathematics) education (Hernandez, 2013; Villegas and Lucas, 2002). Therefore, it is necessary and urgent to promote the decentring of engineering education beyond the technical dimension (Goldberg, 2019; Kamp, 2016; Splitt, 2003).

Dürr (1999) defends the need to change the dominant perspective on engineering, highlighting the need to move from the technical-scientific dimension to the ethical one. He analyses whether technical-scientific knowledge in practice is used to promote social justice and the common good, or whether, on the contrary, it is used without conscience for the economic benefit of some sectors that benefit from hyper-consumerism that destroys nature. Dürr (1999) argues that the mission of engineers must be to solve the global problems that today affect and threaten humanity, but that this must be assumed in an explicit and committed way, always considered by ethical reflection. In this line, he criticises the dominant paradigm: the main objective must be 'to improve the quality of our life and not transform the matter of our Cosmos into consumer goods' (Dürr, 1999: 210). Nussbaum (2010) also defends the importance of education decentralising from an economic and productive perspective. Conlon (2013) considers that it is necessary for engineering to incorporate a capacity for ethical self-reflection on the consequences of its action, thus assuming responsibility for both the present and the future.

Decentralising the dominant engineering paradigm, and broadening it to a responsible and culturally responsive perspective, may be a factor in attracting more women to this area (Monteiro et al., 2021). The limited, strictly technical, view of engineering action, disconnected from its consequences for society, humanity and the environment, may be a factor that contributes to few women choosing some areas of engineering. This is because women tend to prefer professional areas of direct intervention with people, or which contribute to the common good and to improving living conditions, or which involve caring for others or nature (Silbey, 2016). These dimensions are usually absent from the curricula of electrical, mechanical and computer engineering, which are also the areas least chosen by women (Bruning et al., 2015). The increase in the presence of women in the areas of engineering in which they are mostly absent could also redirect engineering towards new perspectives, so that its action is placed more consciously and responsibly at the service of the common good (Monteiro et al., 2021). In this regard, Silbey (2016: n.p.) recognises that:

> women, more often than men, add that they want to become socially responsible engineers, working to solve major problems and making a difference in people's lives – which is consistent with other research showing that women are significantly more likely than their male counterparts to be interested in engineering work that is 'socially conscious' (i.e., specializations such as environmental vs. electrical engineering).

Thus, decentring from the dominant paradigm is also important and necessary for engineering to be more inclusive, contributing to a culturally responsive engineering education.

In this same sense, Raworth (2017) argues that it is necessary to replace 'brain-machine' thinking with 'brain-garden' thinking, centred on care and surveillance, which implies ceasing to see the economy, nature, production, economic growth or technological evolution as machines that have a growing and self-regulating movement of their own. In this new perspective, replacing a passive position that allows itself to be dragged by the system and that sees the future as an inevitability, the economist and the engineer begin to assume an active role in the present, of careful, ethical and responsible construction of the future. Change implies becoming aware of the consequences of one's action or omission on the economic system, and its implications for the sociopolitical–cultural–environmental whole. It also involves reflecting on the objectives to be achieved, and realising that some objectives are incompatible with each other (for example, infinitely increasing economic growth and environmental balance), implying ethical, responsible and sensible choices.

In this context, we need to train engineers who are responsible and sensitive to the human and planetary challenges we face, and who pay attention to all inhabitants of Earth (Raworth, 2017). With this objective, Felber (2019) considers it essential to incorporate into engineers' training behaviours and values that promote the common good. To do this, it is necessary to take into account that all dimensions of nature and the human being must be considered and given attention and care (Raworth, 2017). To do this, it is necessary to analyse, study and reflect on the present, taking into account the lessons of the past, with the aim of preparing ethically and responsibly for the future (Jonas, 2015). Thus, contributing to a culturally responsive engineering education, opening up to different points of view and contemplating the perspective of social justice (Hernandez, 2013).

In this line, Hansen (2002) also argues that it is essential to promote the development of ethical and philosophical reflection, so that students understand the relationships between technology, science and ethical values to prevent the dangerous instrumental use of scientific knowledge and technology (Ings, 2017). This openness and reflection are essential for more culturally responsive engineering.

Thus, decentring from the dominant paradigm implies:

- recognising and assuming the non-ethical neutrality of engineering – 'Knowledge never is and never can be neutral' (Villegas and Lucas, 2002: xvii) – and educating professionals in this area to act responsibly and ethically (Jonas, 2015)
- recognising the power of engineering action, and how it has been exercised throughout history, including at the economic, social, cultural, political and environmental levels
- recognising its main mission 'to improve the living conditions of humanity' (Ordem dos Engenheiros, 2016: 3, authors' translation), and educating for this mission, and for the different cultural visions of what this mission means
- educating and preparing engineers for ethical responsibility for actions in the present that may harm the future and future generations, and for cultural responsiveness.

In view of this, including ethical education in the training of engineers is essential to enhance the opening up of the dominant paradigm (closed and limited) and to open up a vision of the mission of engineering and the consequences of its action in a holistic and responsible way. This allows educating for conscious and responsible decision-making, critically and ethically weighing the potential consequences that may arise, namely for the most socially disadvantaged and for future generations who do not have a voice in the present (Dürr, 1999; Leonhard, 2016). This holistic and responsible vision implies considering the different 'others' and being sensitive to the different ways in which they can be affected by engineering action, and therefore being culturally responsive. At this point, it is important to take into account that engineering students are among those with the lowest level of empathy (Rasoal et al., 2012), which can make it difficult to open up and understand other people's perspectives. Low empathy makes a comprehensive and in-depth ethical analysis challenging, as it makes it difficult to consider other people's views and to understand their problems and points of view (Miyashiro, 2011). According to Rasoal et al. (2012: 432), it is not clear whether engineering courses attract people with low empathy, or whether the problem lies in the engineering curriculum, which usually does not contribute to developing empathy, because it most often does not include debates or opportunities for students to put themselves in each other's shoes: 'Since this kind of training is not part of the curriculum of the engineering programmes in this study, the engineering students have had less opportunity to improve their empathic skills in their programmes.' The reasons why engineering courses traditionally do not focus on empathy may be rooted in the dominant paradigm. Given this, it is also necessary to include intentional and explicit training to promote empathy in engineering courses (Walther et al., 2017).

To change the dominant paradigm in engineering education beyond the technical dimension, it is fundamental to implement a culturally responsive pedagogy. This can be done through the inclusion of ethical education, mainly through including students' and other people's different perspectives and different cultural visions. This can change the perceptions about the consequences of engineering action and about the mission that engineering must have in society and in the environment. These changes can help to diversify paradigms (particularly in terms of ethical care for the environment and for others), which can attract more students with different perspectives to the engineering area, also contributing to bringing new perspectives on engineering action itself, helping to change the dominant paradigm and contributing to a more culturally responsive approach in engineering.

It is also important to highlight that implementing a culturally responsive pedagogy through ethical education, considering different cultural views and perspectives, can lead to increasing students' empathy and promoting critical consciousness. This can help motivate students to be more sensitive to social justice issues and more committed to their resolution (for which it is important to have respect and understanding for the different perspectives of others). This is even more important considering the central role of engineering in contemporary society, and the low empathy among engineering students. The inclusion in the ethical analysis of the hypothetical perspective of future generations is also important to raise awareness and motivate students towards commitment to sustainability.

Therefore, decentring engineering education beyond the technical-scientific dimension must include ethical education, and therefore the consideration of the different points of view of the various potentially affected parties (groups and/or individuals, and nature, which may be directly or indirectly affected by the positive or negative, present or future consequences of engineering actions), the reflection of values and self-reflection. This contributes to culturally responsive engineering education, which in turn contributes to the promotion of social justice (Bassey, 2020), and to sustainability. Incorporating ethics education into engineering courses is also important for promoting ethical behaviour in the professional practice of engineering, which is fundamental for society to trust the profession (Royal Academy of Engineering and Engineering Council, 2022).

Ethical education

Ethical education has the general objective of promoting the moral and ethical development of students. Piaget (1932) affirms that moral and ethical development occurs progressively, in parallel and in association with cognitive development.

According to Kohlberg (1976), moral and ethical development can be divided into three levels:

1. *Pre-conventional*, based on compliance with moral rules and duties to avoid punishment or receive rewards – heteronomous/extrinsic motivation: At this level of moral development, individuals focus on power and social status. They are unable to distinguish perspectives other than their own in moral dilemmas.
2. *Conventional*, based on compliance with social rules: There is recognition of their role as members of society, and of the need to comply with codes and rules that apply to everyone and are fundamental to the proper functioning of society. At this level, concern for others develops, seeking the proper functioning of society.
3. *Post-conventional*, based on universal principles and values: There is the discovery that there are conflicts between the rules and their practice or intention. The recognition of these conflicts opens space for the appreciation of human rights and universal ethical principles, namely respect for human dignity and justice. At this level, there is adherence to norms and rules if they respect universal ethical principles. There is openness and sensitivity to cultural aspects and diversity of points of view (Lima, 2004).

In the ethical education of higher education students, it is necessary to take into account that students who have different levels of moral development and different cultural backgrounds may coexist in the same class, and that everyone must be included in the process of ethical education.

For Rovira (2003), the involvement of emotions and feelings is fundamental in the process of moral development, which is a construction process carried out by the individual. Rovira (2003) argues that for moral development to occur, it is necessary to develop moral thinking, which is why this is the main objective of ethical education.

In cases where ethical education is already included in engineering courses, this is done using several options, such as a specific curricular unit, an optional curricular unit, extracurricular training, optional lectures, mandatory lectures included in other technical-scientific or soft skills curricular units, distributing the contents across the various technical-scientific curricular units of the course

(Davis and Feinerman, 2012), volunteer actions or other activities (Conlon, 2013). The option of at least one compulsory curricular unit fully dedicated to ethics education seems to be the option that most contributes to the enhancement of this educational component, since it is mandatory, and because it has a specific and explicit space and time in the curriculum (thus, it is considered important and necessary for the professional practice of engineering). The implementation of ethics education that is optional, extracurricular or does not have well-defined content or objectives contributes to increasing the frequent perception among students and teachers that this is an unimportant topic in engineering (Lönngren, 2021), and therefore it is not mandatory. In view of this, the present study considered ethical education in engineering courses as mandatory, with specific curricular units for this purpose.

There is a lack of studies and consensus on the specific contents to be incorporated into this training and how to implement it in practice (Barendregt et al., 2020; Johnston et al., 2000), and on the pedagogical dimension of the ethical education of engineering students, despite there being a large consensus on the importance of including ethical education in engineering courses (Durst et al., 2021; Grohman et al., 2020; Katz et al., 2020; Li and Fu, 2012). This lack justifies the importance of the present study (Finelli et al., 2012), which focuses on the aspect of specific content to be incorporated into ethics education in engineering. The definition of ethical competencies that need to be promoted in engineering ethics education is also fundamental to facilitate their practical implementation and, consequently, to contribute to decentring engineering from the current dominant paradigm.

Objectives and methodology

Thus, with a view to contributing to a culturally responsive engineering education, and to the development of the pedagogical dimension of the ethical education of engineering students, the objective of the present study is to develop a framework of the ethical skills necessary for the professional practice of engineering which encourages responsible professional practice at cultural, social and political levels, and for sustainability.

The methodology used included a systematic literature review, document analysis and conceptualisation to identify (1) the ethical competencies that are necessary for professional engineering practice – scientific publications in the area and documents from entities responsible for the professional practice of engineering (nationally and internationally) were covered – and (2) the different frameworks that helped to structure the results, namely Bloom's taxonomy (Anderson, 2001) and Kohlberg's (1976) levels of moral and ethical development.

The entities responsible for the professional practice of engineering in Portugal are the Ordem dos Engenheiros (Order of Engineers) and Ordem dos Engenheiros Técnicos (Order of Technical Engineers). These two Portuguese orders form the professional regulatory bodies and promote technical regulations in the engineering area, and they define legislation. In the study, the respective codes of ethics and deontology were analysed (Ordem dos Engenheiros, 2016; Ordem dos Engenheiros Técnicos, 2016). These documents are mandatory for all engineering professionals and were published with the power of law. They describe the engineers' obligations towards deontological and ethical duties.

The international entity chosen in our study was the Institute of Electrical and Electronics Engineers (IEEE, 2023: n.p.), because this is the 'world's largest technical professional organisation dedicated to advancing technology' and 'the trusted voice for engineering, computing, and technology information around the globe'. The IEEE is an international reference in several areas of engineering, and its Code of Ethics (IEEE, 2020) is applicable to any area of engineering. The results obtained therefore also apply to the different areas of engineering.

In the methodology, official documents from professional organisations were considered. Because engineering is a profession regulated by law, the change has to start from the current context, to build a change that can be accepted by professional entities (which regulate the profession and accredit engineering courses) and by teachers of engineering courses (who will collaborate or not in the change). The use of official documents from professional organisations shows that even in these documents the importance of ethics is present, which contradicts the dominant paradigm defending ethical neutrality. This opens the discussion for progressive change, because ethics education incorporates new and different perspectives that can contribute to a paradigm shift.

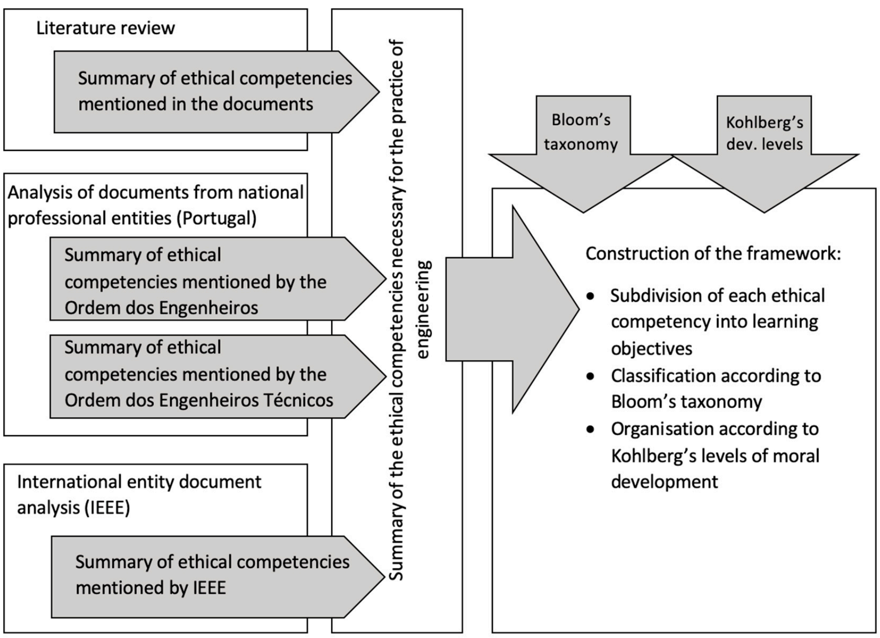
Regarding scientific articles, the inclusion criteria in the analysis included the term 'ethical education' and a reference to ethical skills associated with the practice of engineering. It was therefore expected that the selected documents would defend the vision of non-ethical neutrality in engineering, which is not in line with the dominant paradigm that defends ethical neutrality.

After the collection and analysis resulting from the literature review, a conceptualisation and structuring of the ethical skills necessary for the professional practice of engineering was developed. The collected documents were subjected to content analysis to identify the ethical competencies necessary for engineering graduates with a view to the challenges currently identified concerning the future.

After literature reviews and analysis of the ethical and deontological codes of the Ordem dos Engenheiros, Ordem dos Engenheiros Técnicos and IEEE, the identified ethical competencies were classified into non-exclusive categories, synthesised and grouped. For each type of document, the ethical competencies were identified in each article and document; categories that emanated from the analysis of documents were created; and ethical competencies were classified into non-exclusive categories. After analysing and classifying all ethical competencies identified in all documents of the same type, categories were synthesised and grouped by theme and subject. Sub-skills necessary to put each more complex skill into practice were also identified. For example, the competency of doing 'the right thing, for the right reasons, in the right ways' (Pierrakos et al., 2019: 2) was considered as a complex skill and was classified as the ability to make ethically informed decisions (referred to in 24.1 per cent of the articles analysed), which implies also ethical analysis, reflection and ethical reasoning competencies. This also implies the competency of self-motivation to act in an ethically correct way, which was a competency mentioned in several of the analysed documents. The competency of committing 'to implementing and developing sustainable technological systems suitable for the purposes in view' (Ordem dos Engenheiros, 2016: 9, authors' translation) was also framed in the competency of self-motivation to act in an ethically correct way, which also implies competencies about ethics for sustainability. The competency of being 'aware of the effects of the introduction of technological systems in the social, economic and environmental context and their impact on the lives of future generations' (Ordem dos Engenheiros, 2016: 9, authors' translation) was attributed to the classification 'knowing how to estimate and understand the complexity and potential scope of the consequences of engineering action'. The set of category groups constitutes the summary of the ethical competencies necessary for the practice of engineering presented in the results.

The construction of the framework included the proposal of a set of pedagogical objectives to achieve each of the identified ethical competencies. Each objective was classified according to Bloom's taxonomy (Anderson, 2001) and organised according to Kohlberg's (1976) levels of moral development. Figure 1 shows the synthesis of the methodology used. The framework was established using a practical case of a curricular unit of ethics education of an electrical engineering course at a Portuguese higher education institution.

Figure 1. Summary of the methodology used



Results

The systematic literature review process to identify the ethical skills necessary for the practice of engineering was carried out on the B-on and Google Scholar platforms using the terms 'ethics education' and 'engineering' (only in English), and subsequently filtered taking into account the reference to ethical competencies required for engineering graduates with a view to the challenges of the future. This resulted in 28 scientific articles and 1 doctoral thesis (Monteiro, 2021b). In each document, the ethical competencies that should be promoted in engineering courses were identified. Table 1 shows the summary of the ethical competencies mentioned in the 29 documents studied, referring to the number of documents and the number of documents that refer to each of the identified categories.

Table 1. Summary of the categories of ethical competencies mentioned in the 29 documents studied, referring to the number of documents that refer to each of the competencies (Monteiro, 2021b)

Competency categories	Number of documents
Make ethically grounded professional decisions based on ethical and critical reflection, even in the face of complex and ill-structured problems	26
Understand and assume professional and ethical responsibility, striving to act ethically	20
Identify ethical problems at the environmental and social level and be able to empathise with others	15
Consider several points of view and perspectives in the analysis of problems – know how to work in multidisciplinary teams	14
Understand the mission of engineering in society and commit to individual and community well-being	12
Recognise and understand the negative impacts of technological innovations and the ethical dimension associated with it (recognise and understand the ethical limits of science and technology)	10

Analysis of the ethical and deontological code of the Ordem dos Engenheiros (2016) made it possible to identify five categories that synthesise the ethical competencies referred to in the analysed document (Monteiro, 2021a). Table 2 shows the summary of the analysis carried out.

Table 2. Set of five non-exclusive categories that emerged from the analysis, and the number of references in the analysed document – the ethical and deontological code of the Ordem dos Engenheiros (2016)

Competency categories	Number of occurrences
Have personal motivation to act ethically	70
Know and understand the ethical values involved in the practice of engineering and recognise and understand the ethical dimension of engineering action	52
Know how to analyse critically and ethically, argue and substantiate, communicate and dialogue in the field of ethics	41
Know how to estimate and understand the complexity and potential scope of the consequences of engineering action	31
Know, understand and know how to apply the principles of ethics for sustainability	14

Analysis of the deontological code of Ordem dos Engenheiros Técnicos (2016) allowed the identification of seven categories that summarise the ethical competencies referred to in the analysed document (Monteiro and Sousa, 2022b). Table 3 shows the summary of the analysis carried out.

Table 3. Summary of the set of non-exclusive categories identified in the deontological code of Ordem dos Engenheiros Técnicos (2016), and the number of times each competency is mentioned in the document

Competency categories	Number of occurrences
Have personal motivation to act ethically	79
Know how to analyse and substantiate based on aspects/concepts in the field of ethics	39
Understand ethical values and concepts	21
Know the standards and legislation in the area	19
Recognise individual professional responsibility	13
Know how to estimate and understand the complexity and potential scope of the consequences of professional performance	7
Know and understand how to apply the principles of ethics for sustainability	1

The analysis of the IEEE (2020) Code of Ethics allowed the identification of seven categories that summarise the ethical competencies directly or indirectly embodied in the analysed document. Table 4 shows a summary of the analysis carried out.

Table 4. Summary of the set of non-exclusive categories identified in the IEEE Code of Ethics, and the number of times each competency is mentioned in the document

Competency categories	Number of occurrences
Understand ethical values and concepts, and relate them to the exercise of engineering	21
Have personal motivation to act ethically	19
Recognise individual professional responsibility	13
Know how to estimate and understand the complexity and potential scope of the consequences of your professional action	7
Know the rules and regulations in the area	3
Recognise your limits and be humble to ask for help	3
Know, understand and apply the principles of ethics for sustainability	1

Summary of the ethical competencies necessary for the practice of engineering

After analysing each type of document, it was detected that similar or very close categories were formed in the various types of documents. The various skills referred to in Tables 1–4 (corresponding to the analyses of each type of document) were therefore grouped and summarised into seven main skills:

A. Have personal motivation to make ethically informed decisions, and to act professionally in an ethical and responsible manner
B. Recognise and evaluate the professional ethical responsibility of engineers' individual actions
C. Understand the ethical dimension of the engineering mission
D. Understand and estimate the complexity and potential scope of the consequences of professional engineering action
E. Analyse and substantiate based on the values, concepts and principles of the field of ethics
F. Consider various points of view and perspectives from various areas when analysing complex and poorly structured problems and have empathy towards others
G. Act based on the principles of ethics for sustainability: at a social, economic and environmental level.

The main skills identified were obtained from Tables 1–4, as shown in the example of Competency B, which joins the competencies: 'Recognise individual professional responsibility' from Table 4; 'Recognise individual professional responsibility' and 'Know the standards and legislation in the area' from Table 3; 'Know and understand the ethical values involved in the practice of engineering' from Table 2; and 'Understand and assume professional and ethical responsibility' from Table 1.

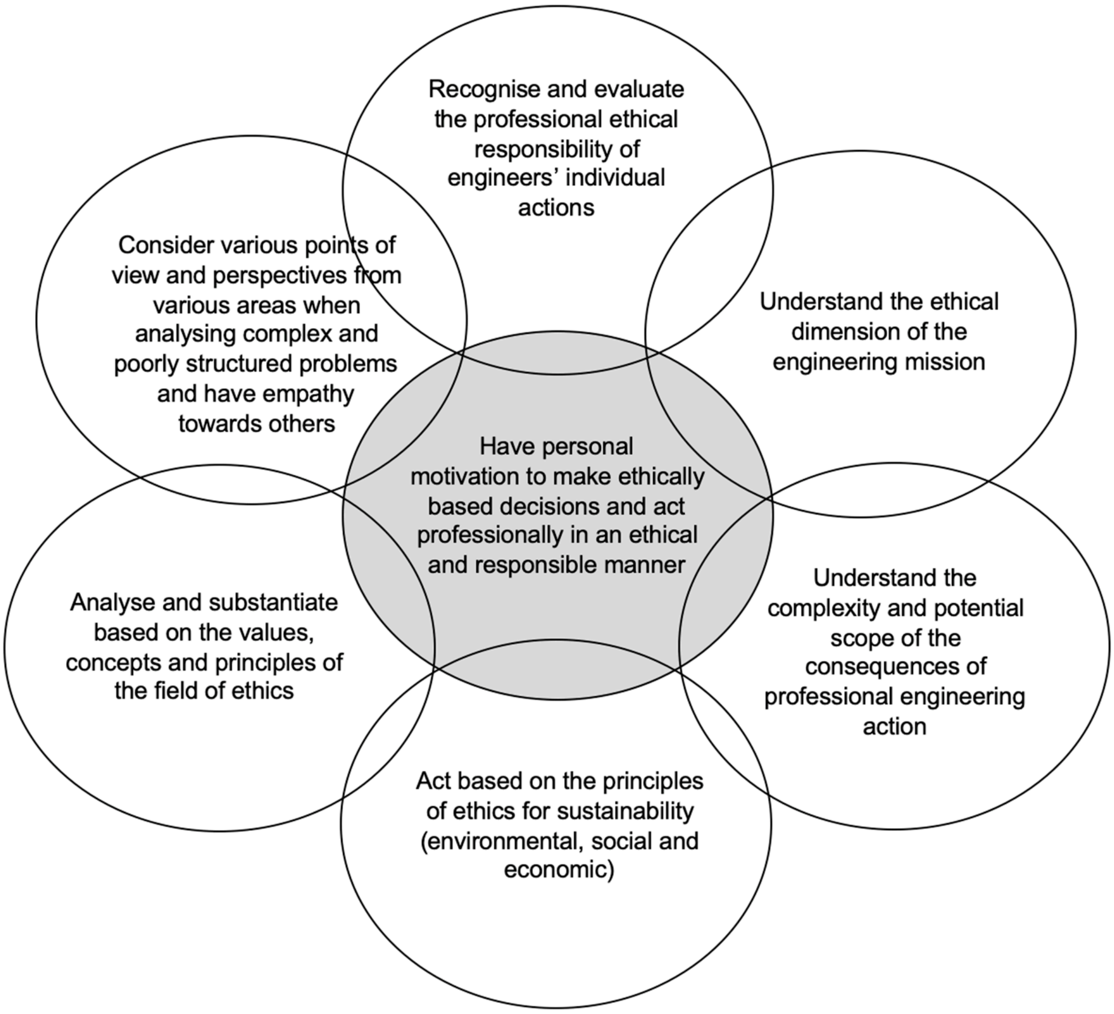
The identified competencies involve the cognitive (intellectual learning) and affective (awareness and integration of values) domains of Bloom's taxonomy (Anderson, 2001). They also involve moral and ethical development. Competency A ('Have personal motivation to make ethically based decisions and act professionally in an ethical and responsible manner') implies personal moral and ethical development (Kohlberg, 1976), and the integration of values at the personal level and intrinsic motivation to act ethically. It therefore involves the affective domain of Bloom's taxonomy (Bloom et al., 1956), and differs from other skills, which mainly focus on the cognitive domain. Taking into account the characteristics of Competency A, this was considered as a central competency (purpose) that can be achieved indirectly from the remaining competencies. According to the Royal Academy of Engineering and Engineering Council (2022: 5), 'Demonstration of ethical behaviour is specifically mentioned for all categories' in 'setting the standards of competence that must be demonstrated by those seeking registered status', and it is also considered a core competency by the Royal Academy of Engineering and the Engineering Professors Council in the UK.

It was considered that personal motivation to make ethically based decisions and to act professionally in an ethical and responsible manner is more likely if: (1) it is recognised that the practice of engineering involves ethical responsibility, at both the individual and the collective level; (2) it is recognised that the consequences of engineering action can be dangerous and unfair; (3) one feels capable of understanding and using the language and concepts of the field of ethics; (4) one manages to carry out an ethical analysis applied to a concrete situation (albeit complex and open); and (5) one understands the responsibility and preponderant role of engineering in the issue of unsustainability/sustainability. In other words, the central Competency A is achieved through the progress of the remaining competencies.

Figure 2 highlights the centrality of Competency A and the fact that it is interrelated with all the other competencies, which constitute a contribution to its development and, at the same time, which are enhanced by the personal development of the central competency (the fact of increasing intrinsic motivation and personal commitment help the learning process of each of the other skills). The Royal Academy of Engineering and Engineering Council (2022) report this as well.

According to Son (2008), engineering ethics education should include the dimension of micro-ethics (understood as being 'concerned with individuals and the internal relations of the engineering profession' [Herkert, 2001: 403]) and macro-ethics (understood as the 'collective social responsibility of the engineering profession and to societal decisions about technology' [Herkert, 2001: 403]). In the set of competencies presented in this framework, the two dimensions are included. For example, Competency B ('Recognise and evaluate the professional ethical responsibility of engineers' individual actions') falls within the domain of micro-ethics, and Competency D ('Understanding and estimating the complexity and potential scope of the consequences of professional engineering action') falls within the domain of macro-ethics. The educational process was designed to begin with the dimension of micro-ethics (B), after which stage C ('Understanding and justifying the ethical dimension of the engineering mission') allows the breadth of analysis to be broadened, moving from micro-ethics for the macro-ethical perspective. Figure 2 also highlights that the different skills are interrelated and interdependent.

Figure 2. Summary of the ethical skills necessary for the professional practice of engineering, highlighting their interrelationships

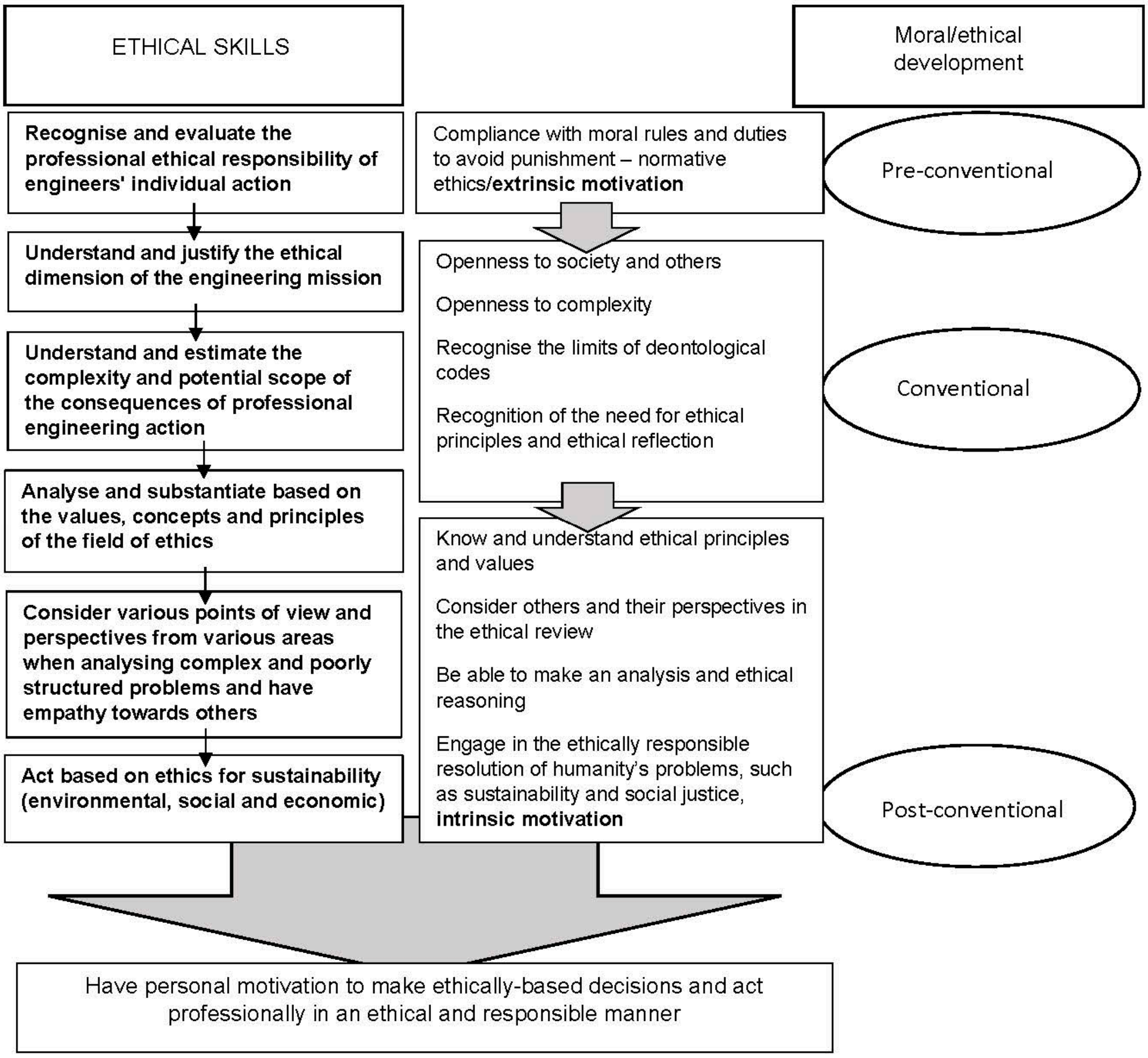


The order of the skills shown in Figure 3 was based on the levels of moral and ethical development defined by Kohlberg (1976), which were adapted as a reference model for the evolution of students' professional ethics. Note that students might be at a post-conventional level of moral development with regard to the private–personal dimension of their lives, while being at a pre-conventional level with regard to the professional ethical dimension of engineering, if reflection on ethics in engineering has not been provided, and therefore has not been developed. However, it is expected that a student who is at a post-conventional level of moral development in the private–personal dimension of their life will have an easier time achieving the competencies (namely the central competency) than a student who, on a personal level, is at the pre-conventional or conventional level. For this reason, it is necessary that the objectives help to promote the ethical development of all students, including those who come from a more unfavourable situation, that is, those who start their ethical education from a pre-conventional level of moral development.

To reach the post-conventional level of moral development, it is necessary to recognise the existence of different opinions, perspectives and values, and to have the ability to put oneself in someone else's shoes to better understand their perspective. But decision-making must be based on ethical reflection and commitment founded on universal ethical principles: seeking to act correctly because it is what is right, and not out of fear of punishment, because it is what is socially expected; because of benefits to oneself; or because it is the easiest option. To achieve this, it is necessary to know, understand

and internalise the ethical principles that guide and substantiate ethical reflection and decision-making, as well as to promote knowing how to put oneself in someone else's shoes.

Figure 3. Combination of ethical competencies with the levels of moral/ethical development defined by Kohlberg (1976)



The combination of ethical competencies with the levels of moral and ethical development defined by Kohlberg (1976) is summarised in Figure 3, where it is evident that the various competencies can help the ethical development of students and the desired central competency. Figure 3 also shows a possible sequence for learning skills over time. This order is intended to facilitate the practical implementation of the teaching/learning process, but it may vary according to the pedagogical methods to be used or other criteria. The sequence presented moves from the basics to the most complex, and from the outside (legal impositions) to the objective of adhesion and inner personal significance (which is a process that needs time and the attribution of meaning and valuation).

The location of Competency E ('Analyse and substantiate based on the values, concepts and principles of the domain of ethics') is due to the fact that the main problem identified in the incorporation of ethical education in engineering courses is the devaluation and lack of interest of students in the subject (Hamad et al., 2013; Lönngren, 2021). In this context, it appears that students consider learning concepts in the field of ethics to be of little relevance (Monteiro, 2017), leading them not to start learning planning with this topic and not taking a path that justifies its study. To overcome the problem of students' lack of interest, this topic was included after a process in which students grew aware of the topic and accept it (Competency B). Students recognise that there is professional ethical responsibility in the practice of engineering, and that it is even legislated. They are asked about what engineering is for (Competency C). They are encouraged to answer this complex question by reflecting on the ethical dimension of engineering. They are challenged by the comparison between the theoretical objectives of engineering and the real direct and collateral consequences (Competency D), promoting the appreciation and importance of ethics in engineering. At the end of these steps, students are expected to be already more receptive to the importance of, and the need for, ethical concepts for their future professional practice and for humanity. This topic is therefore located in the sequence in response to this need. The inclusion of this topic is intended to help students organise a system of values and ethical principles, which can facilitate the organisation phase according to Bloom's taxonomy for the affective domain (Bloom et al., 1956).

Proposal of learning objectives

Each of the competencies (excluding the central Competency A) were analysed and broken down with a view to defining learning objectives that would allow the competencies to be achieved, to facilitate application in teaching and learning processes. When defining the objectives, the documents studied and Bloom's taxonomy were considered (Anderson, 2001), either in the cognitive domain or in the affective domain. Figure 4 shows the proposed learning objectives.

Ethical development involves the cognitive dimension and the affective dimension (including emotions, feelings and attitudes) that must be mobilised in the learning process (Rovira, 2003). According to Bloom et al. (1956), learning in the affective domain is carried out in line with the cognitive domain and involves five steps: (1) receiving (awakening the student, who starts paying attention to the topic); (2) responding (the student is predisposed to react or respond, and to increase their level of attention, which becomes more active); (3) valuing (the student starts to value the theme, and looks for answers to the questions); (4) organising (the student organises the values into systems); and (5) characterising (the student internalises the values, and begins to consciously act in accordance).

Engineering graduates are likely to act more ethically and responsibly if they feel more aware of the ethical dimension of engineering and of the potential consequences of their actions, and if they feel capable of ethically understanding and analysing a situation, as well as of building a foundation rationale that supports them in decision making.

For this reason, and to achieve the central objective, the entire learning process also contributes to the development of the affective domain, as it was constructed in such a way as to promote awakening (receiving), raise awareness (responding), promote recognition of need (valuing), foster the discernment of values and structured ethical principles (which enhances the organising) and foster the intention and tools to act ethically (characterising) (Bloom et al., 1956).

To promote development at the level of the affective domain, it is necessary that each stage of the learning process actively involves the student (from a cognitive, emotional, affective and even physical point of view), so that the student is sensitised and reorganises fundamental ethical values by fitting the new realities learned in the process and that they can mobilise to act in a conscious and reflective manner in coherence with the values they have internalised (Bloom et al., 1956). Along these lines, in the framework developed, the learning objectives are subdivided into a sequence that enhances the evolution of learning from the simple (for example, identify the standards and deontological legislation applied to engineering) to the complex (for example, defend, argue and justify based on the standards and legislation), and with a progressive increase in student participatory action (moving from knowing and identifying to evaluating or creating). This enhances the process of the affective domain: receiving (knowing and identifying), responding (for example, explaining), valuing (for example, comparing and valuing), organising (defending or justifying) and characterising (for example, building a foundation that rationally supports decision making) (Bloom et al., 1956). Table 5 summarises the learning objectives and presents a possible classification of Bloom's taxonomy regarding the cognitive and affective domains.

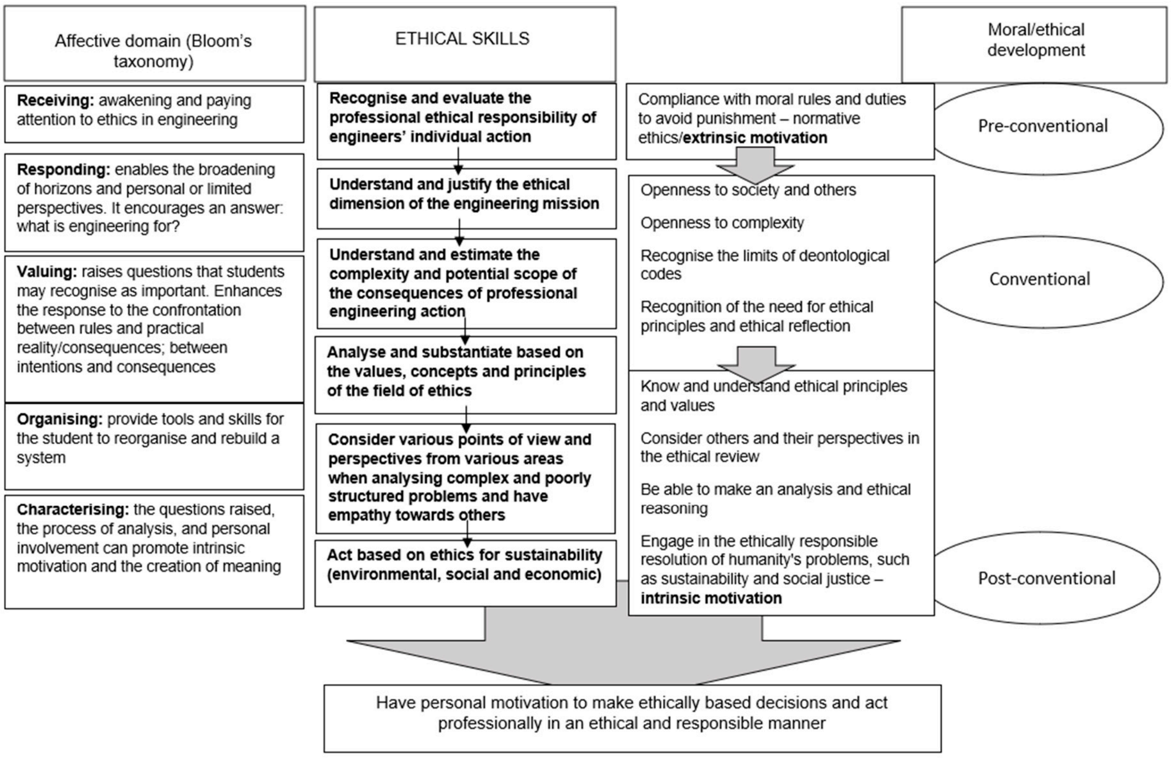
Table 5. Summary of pedagogical objectives and possible classification of Bloom's taxonomy in terms of cognitive and affective domains

Bloom's taxonomy		Ethical skills					
Cognitive	*affective*	**Recognise and evaluate the professional ethical responsibility of engineers' individual action**	**Understand and justify the ethical dimension of the engineering mission**	**Understand and estimate the complexity and potential scope of the consequences of professional engineering action**	**Analyse and substantiate based on the values, concepts and principles of the field of ethics**	**Consider various points of view and perspectives from various areas when analysing complex and poorly structured problems, and have empathy towards others**	**Act based on the principles of ethics for sustainability (environmental, social and economic)**
Remember	⟵ receiving ⟶	Identify the ethical standards and legislation applied to engineering (duties towards the community, the client, colleagues and the profession; and rights)	Identify the official engineering mission Identify the dependence that contemporary society has on engineering	Identify and describe concrete examples of positive and negative consequences of engineering action throughout human history (past)	Identify values, concepts/principles and ethical perspectives	Identify the groups of different stakeholders potentially affected in specific cases	Recognise the problem of environmental, social and economic unsustainability, and its potential future consequences
Understand	⟵ responding ⟶	Explain the rules and deontological legislation applied to engineering and the difficulties that may be underlying it	Explain how the dependence translates into the public trust that society recognises in engineering	Explain concrete examples of positive and negative consequences of engineering action throughout human history (past)	Explain the different values, concepts and principles, and ethical perspectives	Explain how each group is potentially affected	Explain the complexity of the problem of environmental, social and economic unsustainability, and its potential future consequences
Apply	⟵ valuating ⟶	Apply the norms of ethical and deontological codes to concrete cases and identify conflicts that may exist	Show with concrete cases how public trust applies to engineering	Demonstrate how in contemporary times, engineering action can also cause negative and positive impacts (present)	Apply the language, values, concepts and ethical perspectives to concrete cases in an appropriate way	Apply to concrete cases of past, present and future engineering action	Demonstrate the ethical dimension of unsustainability and sustainability
Analyse	⟵ organising ⟶	Analyse practical cases (including conflicts) from the point of view of individual professional ethical responsibility (differentiate, compare)	Analyse the concepts of 'improving the living conditions of humanity' and 'public trust' and identify their ethical dimension	Compare current engineering actions and their potential consequences with cases relating to the past	Differentiate, compare and explain practical cases, taking into account the ethical concepts and perspectives studied and using the language of the field of ethics	Compare and assign value to the different perspectives	Analyse the causes of the problem of unsustainability and establish cause–effect relationships
Evaluation		Defend, argue And justify based on rules and legislation, in specific cases	Justify why engineering is a profession of public trust, therefore it has a strong ethical component	Debate and value the consequences, justifying the position on the benefits/harms of a given action	Defend and justify a certain ethical position in the face of practical or theoretical cases using the ethical concepts studied and the language of the field of ethics	Justify final decision on the ethical dimension of an engineering action analysed	Evaluate the role of engineering in the problem of unsustainability/ sustainability
Create	⟵ characterising ⟶	Summarise the deontological principles applied to engineering and the conflicts that may occur	Combining the limits of deontological codes with the ethical dimension of the engineering mission – explain why deontological codes are important but insufficient	Formulate well-founded predictions for possible future consequences (positive and negative) of engineering action	Combine ethical concepts and their language with concrete examples of positive and negative consequences of engineering action and its mission to build ethical rationale	Propose changes to the engineering action (analysed) to take into account the interests of all those potentially affected and mitigate its negative effects, taking into account the language of ethics and the mission of engineering	Build a proposal for an ethical framework for engineering with a view to sustainability (environmental, social and economic)

The development of the affective domain, in the present framework that has been constructed, is developed in each of the stages of the learning/development process associated with each of the competencies (shown in Table 5), but also throughout the macro-learning process that constitutes the evolution of different skills (shown in Figure 4).

To achieve the central competency/purpose ('Have personal motivation to make ethically based decisions and act professionally in an ethical and responsible manner'), it is desirable that the student reaches the level of characterising (from the point of view of Bloom's taxonomy for the affective domain [Bloom et al., 1956]) and the level of post-conventional moral/ethical development (Kohlberg, 1976). To achieve this, it is necessary that during the educational process, the student attributes meaning and values, and internalises them, promoting the development of intrinsic motivation. To do this, the student must be very actively involved and committed to the learning process. For these purposes, active pedagogical methodologies are the most appropriate option, as they promote the active involvement of students in the learning process (Rieckmann, 2012). Active pedagogical methodologies are student-centred, where students are encouraged to discover and build their own knowledge; students are also likely to think about their actions and the knowledge discovered, which engages them in the learning process (Konopka et al., 2015). These methodologies 'help students to critically or creatively think, talk to classmates or to the entire class, express ideas through writing, explore personal attitudes and values, provide and receive feedback or to reflect on their learning process' (Konopka et al., 2015: 1540).

Figure 4. Summary of skills and possible classification of Bloom's taxonomy regarding the affective domain



The framework presented should be adapted according to the year of study in which ethics education occurs (since this is related to the students' training level and maturity) and to the training time available for ethics education, because this may influence the possibility of achieving the defined objectives.

To illustrate the applicability of the developed framework to an ethical education curricular unit, Table 6 shows a possible summarised plan of general nature in engineering. It was applied to a curricular unit (dedicated exclusively to the area of ethical education) that is part of an electrical engineering course. The plan was developed for 15 weeks of classes.

Conclusions

The role of engineering in contemporary society and in building the future is a reason for the importance of promoting culturally responsive engineering education. To do so, it is necessary to decentre engineering from the current dominant paradigm. Incorporating ethics education into engineering training can help change the dominant paradigm, and can contribute to a more culturally responsive engineering education and a more ethically responsible professional engineering practice. In this sense, this study aimed to develop a framework of the ethical skills necessary for the professional practice of engineering which encourage responsible professional practice at cultural, social and political levels, and for sustainability.

Table 6. Possible summarised plan for classes that resulted from the application of the developed framework to an ethical education curricular unit of an electrical engineering course

Lesson	Competence	Pedagogical objectives	Possible guidance for classes
1	Recognise and evaluate the professional ethical responsibility of engineers' individual action	Identify the ethical standards and legislation applied to engineering (rights and duties towards the community, the client, colleagues and the profession).	Game-based Learning: Escape room board game to motivate, raise awareness, discover and know the deontological codes (Monteiro and Sousa, 2023).
2		Explain the rules and deontological legislation applied to engineering and underlying difficulties. Apply the norms of ethical and deontological codes to concrete cases and identify conflicts that may exist. Analyse practical cases (including conflicts) from the point of view of individual professional ethical responsibility (differentiate, compare).	Each group builds an argument to defend or accuse one of the game's characters: are they guilty of unethical behaviour or not? What codes were violated? Are there code conflicts? Why? Write arguments based on the deontological codes (group works accompanied by the teacher).
3		Defend, argue and justify based on rules and legislation, in specific cases. Summarise the deontological principles applied to engineering and the conflicts that may occur.	Presentations by each group and final decision by voting or general discussion and clarification of doubts + debate. Write a summary of the most important aspects of ethical codes and the conflicts that may exist within them.
4	Understand and justify the ethical dimension of the engineering mission	Identify the official engineering mission. Identify the dependence that contemporary society has on engineering. Explain how the dependence translates into the public trust that society recognises in engineering. Show with concrete cases how public trust applies to engineering. Analyse the concepts of 'public trust' and identify their ethical dimension.	Micro-activities using digital platform(s), including social media – research, form opinion, write (short) text, present slides, share and debate on the following challenges: - You are going to be an engineer: what is engineering for? - Engineering is important in people's lives: exemplify this importance. - People fully trust and are dependent on engineering: what is public trust? - Discover the official mission of engineering.
5		Analyse the concepts of 'improving the living conditions of humanity' and 'public trust' and identify their ethical dimension. Justify why engineering is a profession of public trust, therefore it has a strong ethical component. Combining the limits of deontological codes with the ethical dimension of the engineering mission – explain why deontological codes are important but insufficient.	- The mission according to the professional Order(s) of Engineers. - What does it mean to 'improve the lives of humanity' – 'improve' relates to ethics - Are ethical codes sufficient?
6	Understand and estimate the complexity and potential scope of the consequences of professional engineering action	Identify and describe concrete examples of positive and negative consequences of engineering action throughout human history (past). Explain concrete examples of positive and negative consequences of engineering action throughout human history (past).	Did/does engineering fulfil its mission? Debate: - Examples of things that engineering has already done: identify positive and negative consequences that resulted of engineering in general and of the specific area. - Case analysis: the example of the Ford Assembly Line production that almost led to the extinction of the Zápara people and relate to general concepts of automation, industrial production and industrial management.
7		Demonstrate how, in contemporary times, engineering action can also cause negative and positive impacts (present). Compare current engineering actions and their potential consequences with cases relating to the past. Debate and value the consequences, justifying the position on the benefits and/or harms of a given action. Formulate well-founded predictions for possible future consequences (positive and negative) of engineering action.	Debate past, present and future in relation with following issues: - Did the problems only exist in the past? Identify current cases of positive and negative effects. - Justify the position on the benefits and/or harms of a given engineering current identified action. - What will be the consequences for the future? Example study case: mobile phones, internet, industrial automation, various methods of producing electrical energy or electric vehicles among others. - Identify possible positive and negative consequences (in present and future) of one technology.

8	Analyse and substantiate based on the values, concepts and principles of the field of ethics	Identify values, concepts, principles and ethical perspectives. Explain the different values, concepts, principles and ethical perspectives. Differentiate, compare and explain practical cases taking into account the ethical concepts and perspectives studied and using the language of the field of ethics. Defend and justify a certain ethical position in the face of practical or theoretical cases using the ethical concepts studied and the language of the field of ethics.	Present and debate: - How to decide whether a certain technology is beneficial or not? The need for ethical justification. - Ethical values: theoretical and practical examples. Present 4 ethical perspectives: virtue ethics, duty ethics, utilitarian ethics, ethical subjectivism. - The ethics of the philosopher Thomas Aquinas. - The case of the 'bakers' and the role of intention – debate. - Case of the 'shipwreck in the river' and intention versus consequences.
9		Apply the language, values, concepts and ethical perspectives to concrete cases in an appropriate way. Combine ethical concepts and their language with concrete examples of positive and negative consequences of engineering action and its mission to build ethical rationale.	Research an engineering practical case (mobile phones, internet, industrial automation, various methods of producing electrical energy, electric vehicles, etc), seeing them through each of the different ethical perspectives. Decide one practical case, substantiating based on each perspective.
10	Consider various points of view and perspectives from various areas when analysing complex and poorly structured problems and have empathy towards others	Identify the groups of different stakeholders and potentially affected in specific cases. Explain how each group is potentially affected. Apply to concrete cases of past, present and future engineering action. Compare and assign value to the different perspectives.	Analyse a real case (example: smart grids, smart meters): - Identify directly affected people, groups or nature, possibly affected or indirectly affected (present and future). - Identify potentially possible consequences for each group. - Identify ethical values at stake in possible choices. Assign weights to each value and compare.
11		Justify final decision on the ethical dimension of an engineering action analysed. Propose changes to the engineering action (analysed) to consider the interests of all those potentially affected and mitigate its negative effects, taking into account the language of ethics and the mission of engineering.	Decide and write a justification based on the ethical principles studied for one of the practical cases. Propose measures to minimise or mitigate the possible negative effects justifying based on ethical values.
12	Act based on the principles of ethics for sustainability (environmental, social and economic)	Recognise the problem of environmental, social and economic unsustainability and its potential future consequences.	Board game about sustainability to motivate, raise awareness and discover (Monteiro and Sousa, 2024).
13		Explain the complexity of the problem of environmental, social and economic unsustainability and its potential future consequences. Demonstrate the ethical dimension of unsustainability and sustainability.	Debate: - Complexity of the problem: What are the causes? - What are the consequences? - The ethical dimension of (in)sustainability - Present the principles of ethics of responsibility by Hans Jonas. Present, defend, debate and share findings: - Are sustainability and ethics linked?
14		Analyse the causes of the problem of unsustainability and establish cause–effect relationships. Evaluate the role of engineering in the problem of unsustainability and sustainability.	Analyse, present and debate: - The role of engineering in (in)sustainability. - How technology changes people's behaviour and the 'rebound effect'.
15		Build a proposal for an ethical framework for engineering with a view to sustainability (environmental, social and economic)	Substantiate the decision in a practical case (industrial automation, different methods of producing electrical energy, electrical energy storage methods, electric vehicles, smart grids), based on ethics for sustainability. Build a collective proposal for an ethical framework for engineering with a view into sustainability.

The literature review, and the analysis of documents that regulate the ethical dimension of the professional practice of engineering, allowed us to identify a set of ethical competencies that synthesise what graduates in engineering need to be prepared for the professional practice of engineering. These skills made it possible to identify interrelationships between them, and to organise a possible sequence to structure their learning. To this end, possible sequences of learning objectives were defined with a view to achieving each competency. When building the framework, the main difficulty identified in teaching ethics in engineering was also considered (Lönngren, 2021), as well as Bloom's taxonomy (Anderson, 2001) in its cognitive and affective dimension, and the levels of moral and ethical development (Kohlberg, 1976).

The framework developed and proposed in this study allows us to contribute to responding to a gap that was identified in the literature, relating to the lack of references for the ethical competencies that ethical education in engineering should promote (Katz et al., 2020). It also contributes to making ethical education less abstract, as being abstract is seen as a problem for an area such as engineering, which is very objective (Hamad et al., 2013). By contributing to facilitate the implementation of ethical education in engineering, it also contributes to decentring the dominant paradigm in engineering, as well as to promoting a more culturally responsive engineering education and a professional engineering practice that is more ethically responsible.

It can be concluded that the developed framework allows systematising and interconnecting ethical skills, which can promote and facilitate the inclusion of ethical education in engineering courses. This contributes to promoting an ethically responsible professional engineering practice at a cultural, social, political and sustainability level. The application of the framework allowed structuring a curricular unit of an electrical engineering course. It is a tool that could be very useful to professors of ethics in engineering courses, and to those responsible for building curriculum plans for engineering courses, and it could also contribute to the enhancement of this field of engineering education. This framework will be considered as a basis for future work to investigate which pedagogical methodologies are most appropriate for the different proposed stages of ethical education, as well as for the development of pedagogical tools for each of the stages.

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Declarations and conflicts of interest

Research ethics statement

Not applicable to this article.

Consent for publication statement

Not applicable to this article.

Conflicts of interest statement

The authors declare no conflicts of interest with this work. All efforts to sufficiently anonymise the authors during peer review of this article have been made. The authors declare no further conflicts with this article.

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