Towards Skillful Engineers: A Competence Framework for Engineering Education

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SUMMARY

This research explores the definition of soft skills in engineering education literature and suggests a new framework for understanding the components of soft skills. The study reveals that there is a lack of consensus on what constitutes soft skills and how best to define the term in an engineering education context. The work also highlights the importance of a mutual understanding of the concepts shaping engineering soft skills to ensure meaningful measurement and attainment of competencies. The study aims to pave the way to develop relevant pedagogical interventions and assessment tools for engineering soft skills. The research methodology used in this work is a content analysis on reviewed citations, which extracts explicit definitions and components of soft skills in 93 reviewed publications. We conclude that a precise distinction between knowledge, attitude, personality traits, and skills is necessary to develop engineering soft skills further and align the expectations of the profession and engineering higher education institutions.

INTRODUCTION

Soft skills are increasingly important for engineering students for employability and success in industry (Noordin & Nordin, 2018; Pang et al., 2019; Tadjer et al., 2020). These non-technical skills play a critical role in addressing complex challenges in a globalised market (Bosnić et al., 2019; Martins et al., 2021), including, for example, working successfully on multicultural, multi-lingual, and multi-disciplinary teams, analysing and solving problems, and evaluating the impacts of proposed technical solutions in various contexts (McGunagle & Zizka, 2020).

Evidence of soft-skill competency is therefore a common requirement for accreditation of a higher-education programme(Shuman et al. 2005). However, apart from their inherent difficulty in teaching and measuring (Danaher et al. 2019), a significant barrier remains a lack of a clear consensus regarding their definition: "we are facing a challenge of forming a conceptual categorical apparatus in this field. Some researchers regard soft skills as a kind of superstructure over professional skills. On the other hand, some scientists believe that the concept of 'soft skills' is an enormously versatile and large-scale phenomenon" (Leontyeva et al. 2019). This extends beyond the engineering education context, where despite extensively discussed in literature, soft skills still lack a distinct definition, well-defined scope, standardised assessment methods, and systematic education or training (Matteson et al. 2016). Therefore, it is essential to clarify these skills to develop them further.

However, defining soft skills is complex, as it involves considering a variety of qualities, traits, values, and attributes (Cimatti, 2016). Skills and competencies can be defined in different ways from the perspectives of various stakeholders in academic engineering education, including employers, educational institutions, students, professional bodies, and alumni (Caspersen et al., 2017). The importance and the difficulty of achieving a unified conceptual understanding of engineering soft skills, as well as the lack of a comprehensive framework for engaging different stakeholders of engineering education in the process of defining and identifying engineering soft skills, has motivated the authors to investigate recent engineering education literature on the topic. Only with precise definitions and descriptions, it is possible to meaningfully measure the level of attainment of competencies (Cruz et al., 2020). Hence, the current research investigates the conceptual components of engineering soft skills as the first step towards developing relevant pedagogical interventions and assessment tools.

AIM, OBJECTIVES & RESEARCH QUESTIONS

This study aims to explore the definition of soft skills in engineering education by reviewing relevant literature and building a common framework for understanding components of soft skills in engineering literature. To this end, the following research questions have been formulated to guide the review:

RQ1: What is the definition of soft skills in an engineering education context?

RQ2: What are the components of soft skills in an engineering education context?

As a result, the extent of defining soft skills among engineering publications that discuss the semantics of soft skills can be measured. These research questions also intend to investigate the present understanding of the definition of soft skills in the engineering context and can contribute to forming a holistic approach to engineering education.

METHODOLOGICAL APPROACH

A systematic literature review (SLR) is a structured way of summarising and assessing existing evidence on a specific topic. It aims to make the review more reproducible and less biased (Clarke., 2012). SLRs differ from other "evidence synthesis" types, such as scoping, rapid, and integrative reviews, because they have different methodologies (Grant & Booth, 2009). Systematic reviews are mainly used in health and medicine, using protocols like PRISMA. However, there is a growing trend in other disciplines, including engineering education, to conduct systematic-like reviews and develop related protocols (Keele, 2007).

Steps for conducting a systematic literature review in engineering education include:

- Defining the research question
- Developing inclusion criteria
- Searching for relevant literature and selecting sources
- Extracting data from selected sources and interpreting the results (Borrego et al., 2014; Keele, 2007; Power, 2021).

INCLUSION AND EXCLUSION CRITERIA

The inclusion criteria included relevance to engineering education and discussion of non-technical skills, specific non-technical skills, or assessment methodology related to engineering at higher education levels. Exclusion criteria were applied to ensure the selected documents met the research question's relevance and inclusion criteria. Work outside of a higher education environment and publications about the technical details of developing an educational online platform were excluded. Literature reviews and book chapters were also excluded. A total of 93 publications were reviewed. A summary of the criteria can be seen in Table 1.

Table 1. Summary of Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Discusses engineering education?	Relates to policy development?
Is a peer-reviewed journal or conference publication?	Is set outside a tertiary / higher education environment?
Is authored between 2018 and 2022?	Is a literature review?

Discusses at least one of the following topics: non-technical skills, a specific non-technical skill, an assessment methodology?	Is a book chapter?

DATA COLLECTION

The Boolean query reported in table 2 was created to identify publications that discuss assessment tools related to engineering non-technical skills and the non-technical skills required by engineers. Three databases were searched: Web of Science (WoS), Institute of Electrical and Electronics Engineers Explore (IEEE Explore), and Education Resources Information Centre (ERIC). The same search criteria and Boolean query were used for all databases, except for IEEE Explore, which had limitations on wildcards in its advanced search.

Table 2. Boolean queries used in this review, with publication date filtered between 2018-2022

Database	Query
WoS	"engineer*" AND (("soft skill*") OR ("non-technical skill*") OR ("transferable skill*") OR ("generic skill*") OR ("non-cognitive Skill*") OR ("employability skill*") OR ("Life Skill*")) AND (("assess*") OR ("evalu*") OR ("mark*") OR ("measur*"))
IEEE	"engineer*" AND (("soft skill*") OR ("non-technical skill*") OR ("transferable skill*")) AND (("assess*") OR ("evalu*") OR ("mark*") OR ("measur*"))
ERIC	"engineer*" AND (("non-technical skill*") OR ("non-technical skill*") OR ("transferable skill*") OR ("generic skill*") OR ("non-cognitive Skill*") OR ("employability skill*") OR ("Life Skill*")) AND (("assess*") OR ("evalu*") OR ("mark*") OR ("measur*"))

The search was limited to publications published in English between 2018 and 2022. The initial literature search yielded 379 citations, including six duplicates across the three databases. The number of reviewed publications in each database can be seen in Table 3.

Table 3. Number of generated and eliminated publications for each database

Database	Generated	Rejected	Duplicates	Inaccessible	Reviewed
WoS	344	248	0	16	80
IEEE	31	14	5	0	12
ERIC	4	2	1	0	1

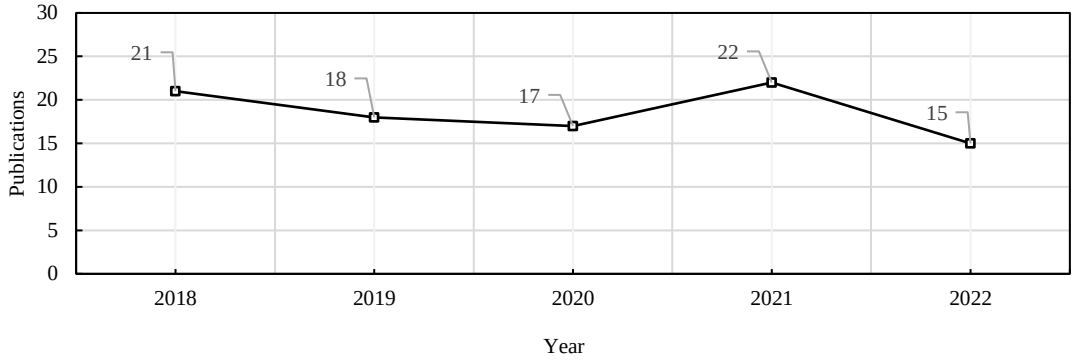
The review included studies from the USA, Spain, UK, Malaysia, and Mexico. The USA had the most studies (14), followed by Spain. The UK, Malaysia, and Mexico each had 7 studies (Table 4).

Table 4. Country of Origin of Included Articles

Country	Number of articles
USA	14
Spain	9
UK, Malaysia, Mexico	7
Russia	6
Australia, Columbia	4
Croatia, Indonesia	3
Brazil, Germany, Hungary, India, Italy, Oman, China, Poland, Portugal, Turkey, UAE	2
France, Israel, Kazakhstan, Saudi Arabia, Serbia, Sweden, Switzerland, Thailand, Ukraine	1

The distribution of included studies has been uniform, as shown in Figure One.

Figure 1. Number of publications included in the review per year

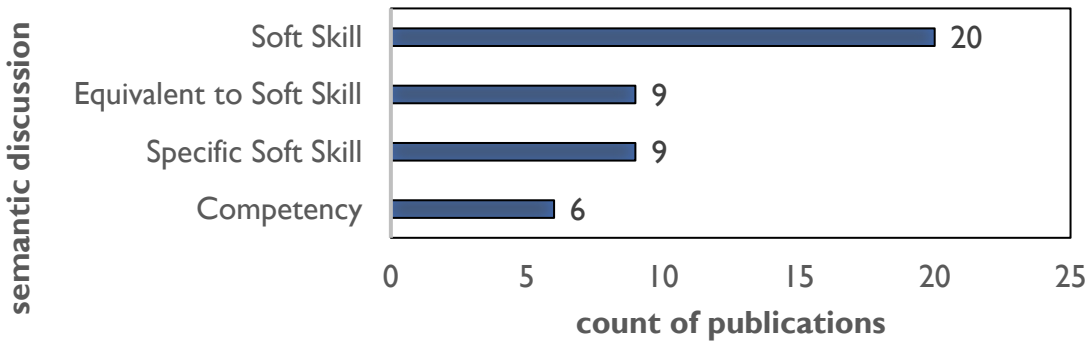


Consequently, a qualitative content analysis was implemented to gather definitions and deduce a hierarchical structure. This content analysis focused on the language used in communication, paying attention to the content and context of the text (Hsieh & Shannon, 2005). There are three approaches to content analysis: conventional, directed, and summative. We consider a summative content analysis that aims to classify large amounts of text into manageable categories and consider the gap mentioned in the engineering literature regarding shaping a mutual understanding around the conceptual understanding of engineering soft skills (Hsieh & Shannon, 2005).

KEY FINDINGS

Of the 93 reviewed publications, 53% did not provide an explicit definition for soft skills or equivalent terms. However, 44 publications (47%) did attempt to provide some clarity regarding the terminology of engineering soft skills by defining either (i) a competency, (ii) a specific soft skill, (iii) a term equivalent to soft skill or (iv) the generic definition of "soft skill" (see Figure 1).

Figure 2. the number of publications, among the 93 reviewed citations, that attempted to define soft skills



Six publications attempt to define soft skills through the lens of competencies. It appears that for the authors, a skilful engineer is the same as a competent engineer. Freitas et al. (2018) employed the term "transversal competency" to discuss issues surrounding transversal and transferable skills in Portuguese higher education engineering. According to the authors, transversal competencies are "those competencies that are beyond disciplinary knowledge, not related to the particular technical or scientific nature of the engineering field of the programs, but that can be developed through formal education".

A second group of publications (n = 9) defined a specific soft skill related to the discussion of their publication. For example, Caratozzolo et al. (2019) emphasise the importance of improving the critical thinking skills of Generation Z engineering students through vocabulary and reading comprehension tests. Thus, the authors define critical thinking as "using logic or reasoning to identify the strengths and weaknesses of alternative solutions, conclusions, or approaches to problems".

A third group of 20 reviewed publications provided a definition for soft skills as an independent concept, each highlighting different qualities and characteristics. These definitions are shown in Table 5. It appears that authors do not consider the context specificity of soft skills in different disciplines and professions. For example, while situational awareness is considered an essential non-technical skill for ward-based multidisciplinary healthcare teams (Sutton et al., 2011), none of the reviewed publications mentioned situational awareness as an expected soft skill for engineers.

The plethora of definitions of soft skills in reviewed publications emphasise the importance of discussing an agreed-upon terminology of engineering soft skills before creating viable pedagogical interventions and assessments.

Table 5. Extracted definitions and components of soft skills from engineering education literature

Paper	Definition	Components
(Mourhir & Kissani, 2020)	a set of social, emotional, analytical, and communicational abilities that are not necessarily technical.	Ability
(Almeida & Morais, 2021)	Soft skills refer to the ability to apply in concrete situations of technical, theoretical, or practical knowledge (experience).	Ability, Knowledge
(Barros & Bittencourt, 2018)	"general" abilities that can be applied in a range of contexts, such as effective communication, teamwork skills, problem solving and lifelong learning.	Ability
(Hirudayaraj et al., 2021)	In contrast to technical knowledge or abilities, the term 'soft skills' is used loosely in literature to denote a disparate set of personal attributes, traits, attitudes, and behaviors.	Attitude, Behaviour, Personality Traits
(Andrienko et al., 2021)	the intangible, non-technical, personality specific skills that determine one's strengths as a leader, facilitator, mediator, and negotiator.	Personality Traits, Skill
(Bozic Lenard & Pintarić, 2018)	personality traits and social skills that affect an individual's ability to interact with others.	Ability, Personality Traits
(Leontyeva et al., 2019)	an entirety of post-professional competencies and personal attributes that provide an opportunity to achieve the set goals through effective collaboration with others in a rapidly changing environment.	Personality Traits
(McGunagle & Zizka, 2020)	refers to a broad set of knowledge, skills, work habits, and character traits that are vital to the success in the future world.	Knowledge, Personality Traits, Skill
(Medvedeva & Rubtsova, 2021)	a set of supra-professional skills and personal qualities that contribute to a person's successful interaction in society, effective implementation of hard skills, and achieving success in professional activities.	Personality Traits, Skill
(Tadjer et al., 2020)	Soft skills or social skills have been given many definitions: Pachauri and Yadav (2014) defined soft skills as personality traits, social gracefulness, fluency in language, personal habits, friendliness, and optimism to varying degrees.	Personality Traits

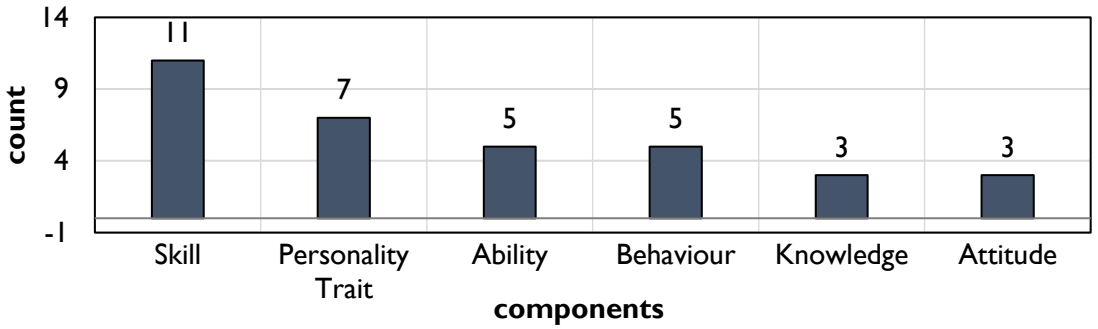
(Lanucha, 2018)	a set of job-related aptitudes, attitudes and behaviors that are important for success in the workplace.	Attitude, Behaviour
(Almeida & Morais, 2021)	behavioral skills that are fundamental in the formation of an individual.	Behaviour, Skill
(Gómez et al., 2021)	the behavioral component expected from a project management engineer.	Behaviour
(Caggiano et al., 2020)	transferable behaviors that can be used in different contexts of life, specifically in highly competitive work scenarios.	Skill, Behavior
(Ferrando-Rocher & Marini, 2021)	the additional or supplementary skills needed by engineers necessary in today's global scenario.	Skill
(Martins et al., 2021)	skills that help us adapt to a certain environment and a set of components like attitude, abilities, habits, and practices.	Ability, Attitude, Skill
(Martins et al., 2021)	soft skills are interpersonal skills that make our communication and relation to other more effective.	Skill
(Arce et al., 2022)	A dynamic combination of cognitive and meta-cognitive skills, and social, and practical skills.	Skill
(Sulistiyo et al., 2018)	basic skills that are important for the absorption of labor and the growth of the individual.	Skill
(Khodeir & Nessim, 2020)	skills, knowledge, and expertise students should be equipped with to succeed in work and life. It is a blend of content, knowledge, specific skills, expertise and literacies.	Knowledge, Skill

DISCUSSION: ENGINEERING SOFT SKILL COMPONENTS

Six concepts have been employed to define soft skills in the reviewed publications*: ability, personality traits, behaviour, skill, knowledge, and attitude.* Illustrating the frequency and

percentage distribution of the six common components of the definition of soft skills, Figure 3 shows that the component with the highest frequency is "skill," mentioned in 11 out of 20 definitions, representing 55% of the total. "Personality trait" follows with seven mentions or 35%, while "ability" and "behaviour" both have five mentions or 25%. "Knowledge" and "attitude" have the lowest frequency, with three mentions or 15% each. This section defines each component for clarity. The following section proposes a hierarchical framework to connect these components.

Figure 3. Frequency of components of soft skills among twenty definitions



Behavior can be thought of as "anything a person does in response to an internal or external event" (Davis et al., 2015). This perspective emphasises that any person's behavior is influenced by other individuals' behaviors, suggesting that behaviors are part of a larger system (Tombor & Michie 2017). While research like (Sheppard et al., 2008) has examined individual behavior within groups, there is a need for further investigation into pedagogical interventions that reinforce the behavioral aspect of engineering soft skills, particularly in measuring both positive and negative behavior.

Building upon this, (Vitello et al., 2021) provide a foundation for understanding knowledge. They define it as the "body of information about a particular field of study or work, which is comprised of facts, concepts, practices, and theories". Knowledge is considered an essential component of a competent engineer (Yother et al., 2022). This accumulated knowledge is used to enhance expertise and proficiency in engineering and is often seen as the foundation for developing new ideas, techniques, and strategies (Yother et al., 2022).

In tandem with knowledge, (Furnham, 2021) defines the concept of ability, stating that "ability refers to the extent to which a person can efficiently carry out multiple processes." This can result from a person's innate abilities or from practice, training, and education (Furnham, 2021). Therefore, and according to this definition it can be said that an able engineer has engineering knowledge and the capacity to perform multiple engineering tasks or processes.

For a holistic engineering education system, it is vital to recognise the significance of "able" engineers and distinguish them from skilful and competent engineers.

Similarly, the role and distinction of traits from other components of engineering non-technical skills, cannot be overlooked. Personality traits, encompassing a person's characteristics, thoughts, feelings, and behaviors, are shaped by a mix of biological, environmental, and cognitive influences, as well as by lifestyle, beliefs, and cultural norms (Hampson, 2017). In engineering education considering personality traits is important to fostering inclusivity and teamwork improvement (Peters et al., 2019). Such importance has been mirrored in setting a set of habits of mind specific to engineers, such as adapting and improving, reflecting the importance of engineering traits towards problem-solving and engineers' approach to work (Lucas et al., 2014).

Additionally, (Haddock et al., 2020), point out that "Attitudes refer to overall evaluations of people, groups, ideas, and other objects, reflecting whether individuals like or dislike them." These attitudes are strong predictors of behavior and represent individuals' feelings and beliefs about various entities. distinguishing attitudes is therefore integral to the broader context of engineering non-technical skills and a holistic engineering education.

Lastly, the concept of skill is based on having knowledge, on the one hand, and on the other hand ability to implement knowledge in a specific context. According to (Matteson et al., 2016), skill is "the ability to access knowledge from a domain-specific knowledge base and use that knowledge to perform an action or carry out a task".

In light of the aforementioned definitions, it becomes apparent that there exists an emergent pattern warranting scholarly attention. In the next section, this study proposes a hierarchical conceptualisation of engineering soft skills, endeavouring to systematically categorise and elucidate the defined concepts in this section. This approach is predicated on the notion that a more nuanced and structured understanding of engineering soft skills will contribute significantly to developing relevant pedagogical interventions and assessment tools and its practical applications in educating better engineers.

SUGGESTING A HIERARCHICAL COMPETENCY FRAMEWORK

According to a recently published report by Cambridge University (Vitello et al., 2021), "competence is the ability to integrate and apply contextually appropriate knowledge, skills, and psychosocial factors (e.g., beliefs, attitudes, values, and motivations) to consistently

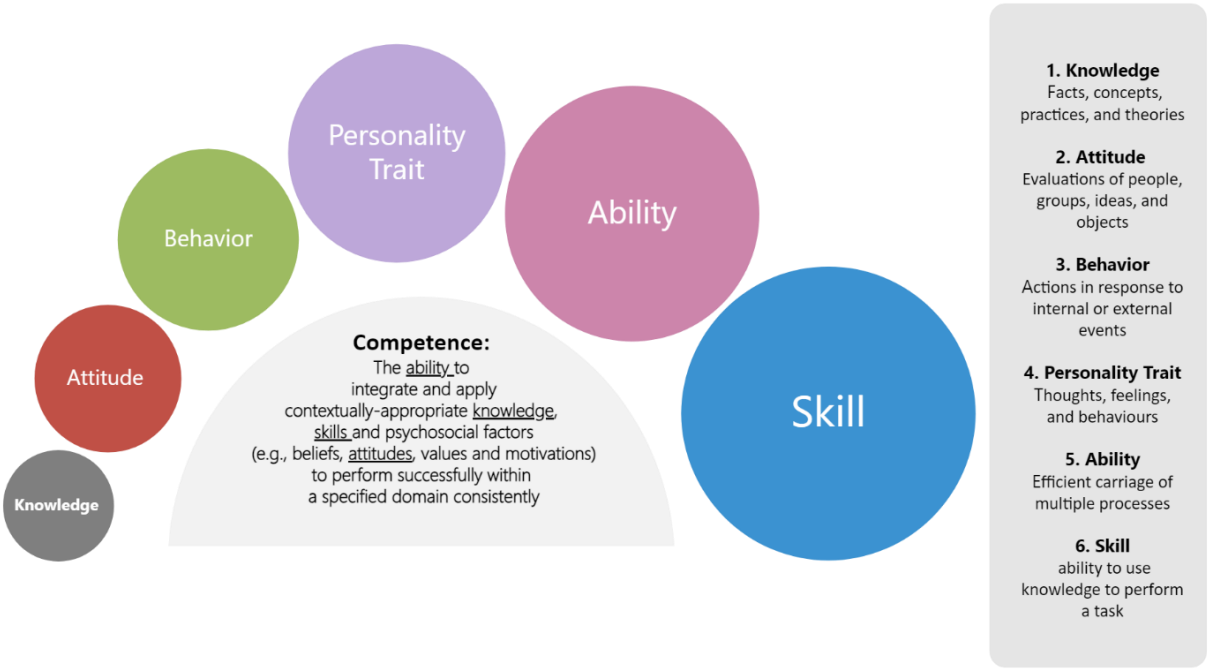
perform successfully within a specified domain". In Sedelmaier & Landes (2018) point of view, competence encompasses the capability to act with proficiency in complicated situations. Such an act in intricate and novel circumstances requires both technical knowledge and non-technical skills. Neither soft skills nor knowledge on its own is competence and so competencies only emerge when both knowledge and soft skills collaborate.

Because competency can gather all components of the soft skill definition provided in the previous section, *we suggest that a competent engineer is the ideal outcome of engineering education systems*. Building a competent engineer starts with transferring the knowledge engineers have established through the discipline's historical development (knowledge stage). The right process of knowledge transformation then builds a set of evaluations about people, ideas, and other objects engineers engage with throughout their professional life (i.e., engineering attitude).

Competence is correlated to "the context, emotional elements, and an ethical, normative component"(Sedelmaier & Landes, 2018) indicating its overall concept on top of skill, behaviour, traits, and knowledge. True knowledge and attitude building should have an external appearance. These external appearances emerge as specific behaviours and will be internalised into characteristics of engineers, showing themselves as personality traits in an ideal form of engineering education.

Soft skills are essential for keeping hard skills up to date in changing circumstances (Cimatti, 2016). The aggregation of knowledge, attitude, behaviours, and personality traits makes an able engineer. A continuously able engineer, over time becomes a skilful engineer: the skilfulness of an engineer can be seen in the efficacy of carrying out multiple engineering processes, showing the suitable personal characteristics exemplified by behaviours using the engineering body of knowledge. A consistent engineering task performance will emerge through years of integrating engineering knowledge, skills, and psychosocial factors (e.g., beliefs, attitudes, values, and motivations). In line with definitions provided in previous section, we propose a hierarchy of competence which represented in Figure 4.

Figure 4. A hierarchical diagram for developing competence in engineers through various factors



CONCLUSION

Based on the literature review and analysis of the components of soft skills in engineering education, there is still a lack of consensus on the definition of "soft skills" and how best to define the term in an engineering education context. Most sources agree on the importance of personality traits, abilities, and behaviours as key components of soft skills, while engineering education is unpropitiatory and focused on knowledge and technical skills.

The hierarchical framework proposed in the discussion suggests that if the ideal outcome of engineering education systems is a competent engineer, more attention should be paid to developing relevant pedagogical interventions and assessment tools for engineering attitudes, behaviours, personality traits and skills as competence is integrating and applying contextually appropriate knowledge, skills, attitudes, behaviours, and abilities to consistently perform successful engineering tasks.

Elucidating the components of soft skills in engineering education is a complex and multi-dimensional task. To develop a competent engineer, it is necessary to have a clear and consistent definition, formalise communication with different stakeholders in engineering education to understand their needs and expectations and implement appropriate pedagogical interventions and assessment tools to reinforce positive behaviours, attitudes, and traits, as

well as integrate engineering knowledge with the aforementioned concepts. This ultimately leads to the development of consistently able and skilful engineers who can proficiently navigate complicated situations, i.e., competent engineers.

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APPENDIX

The dataset for this paper, including a detailed description of included papers, can be found at: https://data.mendeley.com/preview/574pd42zt6?a=6179658d-4afc-4852-9781-36bfb445c573