A Heuristic Model of Non-technical Competences for Engineers

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Abstract: - Engineering education has evolved in the direction of providing students with perfect technical competence. The current paper discusses the non-technical competences of engineers that are crucial to modern professional engineering. Highlighting the traditional competence models, we examine the six most influential non-technical areas of competence for engineers. Based on the corresponding literature, we offer a model of non-technical competences for engineers.

Key-Words: - Non-technical competences, the model of non-technical competences

1 Introduction

The changing nature of engineering work has placed unprecedented demands on engineers and fueled the concerns of engineers' educators. It is argued that engineering is no longer a matter of just engineering [1], as the profession of engineering and the roles of engineers have changed rapidly over the past few decades. The need to educate "holistic engineers" [2], [3], [4] or "global engineers" [5] is widely acknowledged. The "new century engineer" is expected to be technically competent, globally sophisticated, culturally aware, innovative and entrepreneurial, nimble, flexible and mobile [6]. The problems faced by engineers today are increasingly complex and require both strong technical knowledge and skills and an understanding of relevant environmental, social, economic and cultural contexts [7].

Accordingly, there exists considerable consensus that the modern engineering profession requires not only technical excellence, but also some additional, non-technical competences. Moreover, in recent years engineers' educators have accepted the challenge of teaching non-technical competences [7], [8], [9], taking it so seriously that the Association of German Engineers (VDI) suggests that up to 20% of an engineering curriculum should be in non-technical fields such as language training, self-management, personality development, communication skills, project management, economics, and other related topics [11]. Unfortunately, no agreement has been reached regarding what exactly the non-technical skills or competences are in their deeper content. Ongoing debate clearly shows that different researchers and educators understand this issue differently and are offering different "packages" of engineers' non-technical skills [12], [13], [14], [15]. We agree with Deist and Winterton [16] that if a competence is important, its meaning is also important, since without a common understanding as well as the development of appropriate typology of competence, there is little chance of integrating education and training, and aligning both with the needs of labor market.

2 Problem Formulation

In mainstream engineering education literature, there is still confusion in the use of terms such as "competences," "generic competences", and related terms such as "generic attributes", "generic skills" [17], [18]. The ongoing debate about the meaning and definition of engineering competences considers the distribution of skills/competences in various combinations: technical and non-technical [19], [20], [21], [22], [23], [24], [25], [26] or basic and additional [27], or technical and soft [28]. Lists, studies, and applications are often based on similar yet varied constructs, which makes it difficult to implement

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non-technical competences in curricula. We feel that there is a need and the time is right to work out a more integrated framework of engineering non-technical competences that would systematize existing knowledge into a complete approach based on a well-founded theoretical basis. Identifying and delineating the content of those domains helps engineering educators to develop curricula that help students increase their competence in non-technical fields.

3 Toward a More Integrated Framework of Engineering Non-technical Competences

One of the key weaknesses of engineering non-technical competence models used in engineering literature is that the models follow different theoretical approaches to competence. In addition, the exact content of each engineering non-technical competence is vague and undefined. This is a problem facing many of the approaches to engineering non-technical competences, and we suggest that one of the ways to address this problem is to focus more attention on providing a more detailed description as well as classification for different engineering non-technical competences.

3.1 The Definition of Engineering Non-technical Competences

There is an increasing consensus that competence should be defined as "a learned ability to adequately perform a task, duty or role" [29], relating to a specific type of work to be performed in a particular work setting, and integrating several types of knowledge, skills, and attitudes in a dynamic way. Competence is an integrated set of knowledge, skills and attitudes, and its existence and/or the level of acquisition can be proven and evaluated (measured). Competences represent a dynamic combination of cognitive and meta-cognitive skills, knowledge and understanding, interpersonal, intellectual and practical skills, and ethical values. Competences can also be compared to a pyramid made up of a person's opinions and values, skills and knowledge. That which we believe or we know is expressed through our actions. Our opinions and values affect our behaviours and actions, while the experiences we gain through our actions in turn help to shape our beliefs and values (Fig. 1). Competences should be also be distinguished from abilities, personality traits, and other more stable characteristics of the individual. Such dispositions can be seen as the basis for what the individual learns, i.e. knowledge, skills, and attitudes, as well competences. But since the learning process also depends on situational factors and on time, dispositions should not be equated with these learned qualities [29].

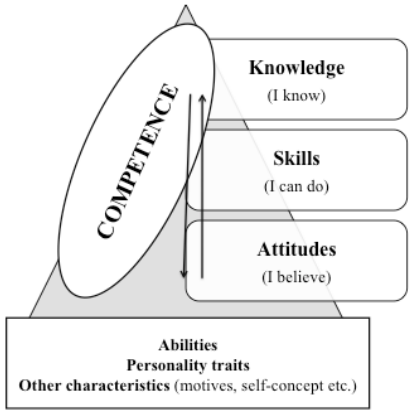

Fig. 1 Competence Pyramid Based on Individual Dispositions

The Tuning-AHELO expert group defines engineering competence as the applying of relevant skills and knowledge in solving problems of interest to an engineer [30]. According to Tuning-AHELO methodology, engineering competences are divided into subject-specific competences and generic (general academic) competences (also called transferable skills - critical thinking, analytic reasoning, and problem solving (Fig. 2).

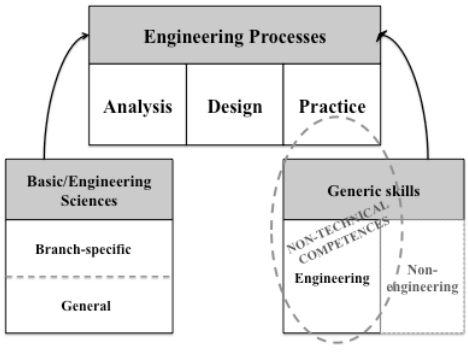

Fig. 2 Non-technical Engineering Competences in OECD Model (modified by OECD Model, 2011)

Subject-specific engineering competences are made up of competences in basic and engineering sciences as well as competence in engineering

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processes (analysis, design, practice). These are based on technical knowledge, understanding, and skills, and therefore are called "technical competences".

Generic engineering competences are those that have great importance to graduates across all different engineering fields, just like generic non-technical competences.

Shifting our focus back to engineers' non-technical competences, we define non-technical engineering competence as "a specific range of non-technical knowledge, skills, and attitudes/value system needed to adequately perform the professional work and professional roles of an engineer." Professional attitudes provide a general framework for a person's decisions and actions. Skills are developed in the process of using knowledge in everyday work practice.

There is a need for explanatory knowledge of human behavior and its context in work, organization, society, and personal as well as interpersonal fields to delineate the range of non-technical of competences. In particular, we are of the position that it is necessary to distinguish skills from competences. From this viewpoint we define a skill as a craft, an excellence in performance that comes from one's knowledge and is used in practice, while competence has a broader meaning that includes skills as one component, i.e. engineering non-technical competences are a specific range of knowledge, skills, and attitudes for adequately fulfilling engineers' professional work and roles. A competence is more than just knowledge and skills; it is a broader concept and involves the ability to meet complex demands by drawing on and mobilizing psychosocial resources (including skills and attitudes) in a particular context.

3.2 A Heuristic Model of Engineering Non-technical Competences

Based on a comprehensive review of research literature and analysis of qualification criteria for engineers that have been prescribed by professional bodies [31], [32], [33], expected outcomes for engineering graduate programs used internationally by bodies concerned with both professional and education [34], [7], and visions of the engineers of the future [35], [36], [37], we offer a heuristic model of non-technical competence domains for engineers (Fig. 3).

Fig. 3. A Heuristic Model of Non-technical Competences for Engineers

The non-technical competences for engineers are divided into the following six domains:

1. Professional ethics competences domain;
2. Personal competencies domain;
3. Interpersonal competencies domain;
4. Leadership, management, and administrative competencies domain;
5. Innovation and entrepreneurial competencies domain;
6. Law and legal system competences domain.

All these competences belong to the fields of humanities and social sciences, therefore calling them non-technical competences is appropriate.

The domains of non-technical competences can be depicted as separate yet having a shared component with their neighboring competences. For example, knowledge and understanding about ethical principles is needed and engineers are expected to have professional ethics in situations when the requirements prescribed by law are open to interpretation (gray areas in the law). In those situations, choosing the best solution in the interests of the client that is also in compliance with the relevant law is an example of how law competences and professional ethics come together. Also, for effective leadership good communication skills are essential, which fall under interpersonal competences.

3.3 The Professional Ethics

An understanding of and commitment to professional ethics is emphasized by all professional associations of engineers and implemented [31], [32], [33] through Codes of

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Conduct. Engineers must have the ability to perform their profession in accordance with rules of good practice and proper behavior, have a responsibility to nature, their life environment, safety and health, and keep the traditional cultural values of the country [38], [39], [40], [41], [42], [43]. To act well in a role of a good professional and a good engineer, it is not enough to just be an ethical person: "Engineering ethics is professional ethics, as opposed to personal morality" [44]. In the engineering profession, ethics questions emerge in almost all fields. "Engineering ethics is that set of ethical standards that applies to the profession of engineering" [45]. Problems may occur when the education of engineering students regarding ethical issues and the realities of contemporary engineering practices are disconnected [46], [47]. Andrews and Kemper [48] saw engineers as essential players in addressing the social challenges of the sustainable development of the twenty-first century, such as international competition, the problems of pollution and waste management, the world problems of overpopulation and shortages of housing, food, and energy, which all have ethical implications. That means that engineers have to understand the non-technical implications of engineering practice and the possible future causes of their activity in order to be socially responsible [49], [50].

Modern practical and professional ethical education sees ethical responsibility as a central concern of the engineering profession and practice and aims to improve student's ethical judgment [44].

There are three important components in this domain of non-technical competence. Ethics of personality mean living honestly and in line with ethical values, being tolerant of differences, including cultural differences, and following general rules of ethical behavior. Professional ethics is adhering to the requirements of engineering ethics, even in situations where work assignments extend beyond the competence of an engineer, for example working out situations that are legally but perhaps not ethically sounds and fulfilling all aspects of accepted assignments. The social responsibility of engineers is their obligation and responsibility to society, socially sensitive actions, and conveying clear information to the public that takes into account the effects of decisions related to science and technology on nature and society.

3.4 Personal Competences

Personal competences are related to the perception of a person's own situation and needs, assuming responsibilities for one's actions, and reflecting on all these aspects in a self-critical and constructive way [51]. These competences contribute to adaptive behavior and productivity in that they counteract undesired influences that may arise from within the person or from the environment, and support volitional behavior. Because they affect goal adoption, pursuit, and disengagement, they are critical for productivity in multiple life domains. The common thread among these attributes is a skill called self-regulation [52], [53].

The four competences in this domain are *(1)* flexibility (adaptability, getting by in new or rapidly changing circumstances, assessing a situation objectively, changing plans if necessary) [54], [55]; *(2)* stress tolerance and coping with stress (stress tolerance, working in a stressful situation, techno-stress, work stress and dealing with burnout) [56], [57]; *(3)* self-management (setting personal goals, setting priorities, using time effectively, evaluating resources realistically, changing activities in response to feedback, learning from mistakes, self-motivation and a positive, optimistic outlook on life, and self-control: the ability to manage one's emotions, calmness and balance, persistence to follow something through to the end) [58]; and *(4)* learning skills and motivation (lifelong learning, additional study, the curiosity that is the basis for ongoing study) [59], [60].

3.5 Interpersonal Competences

Interpersonal competences are those required for relating to other people. They are particularly important in the initiation, formation, and maintenance of interpersonal relationships in various domains of life. Interpersonal competences are used both to express information to others and to interpret others' messages (both verbal and nonverbal) and respond appropriately. Successful interpersonal behavior involves a continuous correction of social performance based on the reactions of others and solving problems associated with social expectations and interactions. The four competences in this domain are (1) communication (successful communication, including in a virtual environment, giving feedback, using language appropriate to the situation, ability to address an auditorium, clear verbal and written self-expression, creating an atmosphere conducive to

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communication) [61], [62], [63]; (2) cooperation and creating relationships (ability to create and maintain good relations, empathy, ability to listen to others and take the needs of another into consideration, creating cooperation networks and participating in them) [64]; (3) negotiation and conflict management (ability to rephrase a problem, help parties reach a helpful solution, the constructive resolution of points of dispute, reaching a consensus) [65], [66]; and (4) influence (consciously shaping an impression, inspiring, convincing, asserting, motivating, involving, delegating, mentoring, and guiding).

3.6 Leadership, Management, and Administrative Competences

Leadership in a broad sense means developing, engaging and inspiring others to bring to life a common vision *via* sharing perspectives and developing and maintaining trust. Leadership attributes that have been found to be effective across most situations include self-confidence and a tendency to be confident in others, optimism and determination, and the ability to be nurturing and offer developmental opportunities to others [67]. Management is the process of working with and through others to achieve organizational objectives in a changing environment. Central to this process is the effective and efficient use of limited resources in the quest for productivity improvement. Competences in this domain include (1) project management (planning out and implementing activities to reach the desired result within the limits of the time schedule, budget and other resources), [68], (2) leadership of an organization or unit (planning, organizing, controlling, directing resources, dealing with crises, directing processes, administering, directing results, delegating, knowing and affecting the culture within the organization, initiating and guiding change, leading meetings) [69], and (3) team leadership (creating and developing a team, initiating work and projects, being familiar with and affecting group processes, leading an interdisciplinary and multicultural team) [70].

3.7 Innovation, Entrepreneurial Competences

Innovation refers to the actions that change what a person or an organization does and the way it does it. It involves a departure from current ways and the replacement of old ways. Micro-views of innovation put the emphasis on the individual and group-level creative processes underlying innovation. Entrepreneurship is the recognition and exploitation of market opportunities [71], [72], [73], [74]. Two competences in this domain are (1) creativity and innovativeness competence (creating visions and strategies for the creation of new products and services and development of new technologies, seeking out solutions to problems, generating new ideas and approaches, finding or seeing innovative solutions, striving for innovation) ; (2) entrepreneurship (recognizing and defining a potential market niche for new products or services, orientation towards meeting the needs of the client, realizing and developing an idea to create an actual product or service, developing products or services that suit or relate to the chosen market niche, willingness to take risks, focused work to meet a goal, finding the resources to carry out ideas).

3.8 The Law and Legal System

Engineers need to be aware of the legal, ethical and social aspects of technology. IN addition to regional regulations (EU, ASEAN), it's necessary that they understand the comparative approach and jurisdictional issues. The professional activities of engineers are directly related to labor law, freedom of speech, corporate law, business law, contract law, anti-terrorism legal regulations, and cyber security, to name just a few. As Zandvoort puts it, "this educational goal requires that systematic attention be given in the engineering curricula to the critical study of the functions and presuppositions of the legal system, including ethical foundations and including a critical assessment of how well the actual legal systems perform their functions" [75].

More specifically, knowledge about intellectual property and patents is relevant because the "proper understanding of patent law can mean the difference between a valuable opportunity and a costly mistakes" [76].

4 Conclusion

In recent years researchers, educators, practitioners, employers, and professional bodies have reached the consensus that in addition to excellent technical competence, engineering also requires some kind of successful non-technical competences. What is still missing is a generally accepted definition of engineering non-technical

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competences, as well as a common understanding of what exactly engineering non-technical competencies are in their content. Even for very pragmatic reasons (e.g. curriculum development and assessing the competence of engineers) it is necessary to find some consensus regarding terms, definitions, and theoretically valid concepts regarding engineers' non-technical competences.

As we used an interdisciplinary approach, it was expedient for several reasons to introduce the term "non-technical competences". First, a heuristic model of engineering non-technical competences includes the areas of science that cannot be unambiguously defined as social, e.g. law, ethics and innovation. Second, the term "social competences" has a different connotation, as it is mainly a synonym for interpersonal competences and therefore is not suitable for a broader meaning. Third, the term "non-technical competences" is already widely used in engineering, including in engineering education.

Thus, engineering non-technical competences are a specific range of knowledge, skills, and attitudes needed for adequately fulfilling an engineer's professional work and roles.

We undertook the task of reviewing the literature and applied findings in the area of engineering non-technical competences, as well as mapping the areas of engineering non-technical competences and the content of these competence domains. The heuristic model of engineering non-technical competences shown in Fig. 2 integrates our interdisciplinary findings.

The model draws six engineering non-technical competence domains and in each domain, in turn, is divisible into several competences. The six domains in a heuristic model are: Professional ethics (includes three competences: personal ethics, professional ethics, social ethics); Personal competencies (includes four competences: flexibility, stress tolerance and coping with stress, self-management, learning skills and motivation); Interpersonal competencies (includes four competences: communication, collaboration, negotiations and conflict management, influence/manipulation); Innovation and entrepreneurial competencies (includes two competences: innovativeness, creativity, and entrepreneurship); Leadership, management and administrative competencies (includes three competences: project management, organization / division management, and team leadership); Law and legal system (includes three competences: intellectual property laws, knowledge of legal issues in engineers' work, commercial law). Each domain, in turn, is divisible into several competencies.

A heuristic model of engineering non-technical competences highlights the need for more large-scale empirical studies in the area of engineering non-technical competences. The number of variables included in this model means that it could be investigated with relatively large samples. Although it would be possible to examine different domains of the model in isolation, for instance, it is possible to study one single engineering non-technical competence domain. In addition to using large samples of engineers, preferably from various fields of engineering, consideration must be given to how long one has worked as a professional engineer. It can be assumed that not all non-technical competencies are equally required during the initial period of an engineer's career. Some non-technical competences, e.g. managerial competences, are required for an engineer's career to progress. In order to find the answers to the assumptions mentioned above and to develop our understanding of engineering non-technical competences, the empirical testing of a heuristic model of engineering non-technical competences has already begun.

Finally, further research is needed on engineering competences more generally. We sectioned off one part of a professional engineer's full set of competences and focused on engineering non-technical competences. However, we are convinced that in real everyday work, engineers use a broad range of competences simultaneously and distinguishing one type of competences is quite abstract even on the analytical level. How different engineering competences are integrated and used in practice, how different competences or combinations of competences support each other and lead for performance, which competences are most crucial for success, with what and how it is possible to compensate for the lack of one specific skill or competence – these questions are promising areas of future research.

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