# Chapter 2
# Literature Review of iKBE Competencies and Systemic Modelling

## 2.1 Introduction

Historically, the main skills engineers need to have are technical disciplinary content knowledge and technical competency; however, concerns of needs of engineers for a variety of non-technical skills can be traced to the early 1980s (Wearne 1984). Engineering in particular and other relevant STEM (Science, Technology, Engineering and Mathematics) fields in general are the most critical sciences for a nation to consider while seeking for or maintaining a Innovation and Knowledge-Based Economy status (NAE 2005, 2004; NRC 2007; Pinelli and Haynie 2010). In this context, the talent and skills requirements of current and future engineers as well as necessary relevant reforms in engineering education curriculum have become a hot topic of investigation during the last 10–15 years. Numerous studies and policy reports have been published mainly in developed countries or emergent economies, such as USA (Duderstadt 2008a), Australia (Rabl and Hillmer 2012), UK (Spinks et al. 2006), Canada (Chan and Fishbein 2009), Malaysia (Abdullah et al. 2007), India (Mishra 2010), and Thailand (Sunthonkanokpong 2011). The majority of studies have investigated needed talent in engineering in general; however, some research has had a more microscopic level, focusing on the required skills in a specific domain of engineering. For instance, studies have been published on skills required in transportation engineering (Skills and They 2009), mechanical engineering (2028 Vision for Mechanical Engineering: A report of the Global Summit on the Future of Mechanical Engineering 2008; Danielson 2011), engineering management (Dudman and Wearne 2003), and civil engineering (ASCE 2007). These studies continue to emphasize that technical content knowledge and competencies are essential for any engineer; however, in addition to being well grounded in mathematics and science, twenty-first-century engineers should be well shaped in broader knowledge base and diverse personal/interpersonal key skills. Such attributes and skills may include the following: teamwork, communication,



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inter/multidisciplinary knowledge, analytical thinking, ingenuity, creativity, technological innovation, business and management skills, leadership, ethics, professionalism, as well as understand work strategies (Anderson et al. 2005; Sheppard et al. 2004; Swearengen and Barnes 2002; Shuman et al. 2005).

This chapter aims to provide a comprehensive literature review on needed skills for graduate and future engineers, in the context of generic skills and employability needs in knowledge-based societies and economies. The review spans over a diverse range of relevant studies, reports, books, conference proceedings, and journal articles. The review findings and contributions can be coined in three main folds: 1—a conceptual ontological framework of engineering skills in the context of generic—and employability—skills of KBSs and iKBEs citizens and workforce, 2—the development of a model of driving forces for focus on shift of needed skills and attributes of engineers, and 3—a global set of 22 mutual common skills, but different in topology, between engineering and generic competencies.

## 2.2 Drivers of Focus on Skills Development in Engineering Education

There have been many drivers for the emergence of research on skills and talent of graduate engineers, and the same drivers have led to identifying the needs of engineering graduates and skills that meet significantly wider needs than ever. These drivers are mainly the following:

- Satisfying industrial needs (Spinks et al. 2006).
- The emerging roles and disciplines of engineering sciences (Tryggvason and Apelian 2006).
- Adapting to highly advanced and complex working environment.
- Contextualizing the generic engineering graduates' attributes in the light of the needs of knowledge-based societies and economies (Male and Chapman 2005).

These factors have been pressing on deploying changes in engineering education systems to meet the emerging needs. The drivers are visually represented in the model-of-four-forces (eng-skills-MoFF) shown in Fig. 2.1 and are detailed in the subsections below.

### *2.2.1 Driver 1: Bridging the Gap with Industry Needs*

The gap between the graduates' actual and industry-desired attributes has been extensively investigated and recognized through numerous studies, mostly surveying engineering employers about their satisfaction with the fresh graduate skills and competencies. The majority of the studies have reported a deficiency in

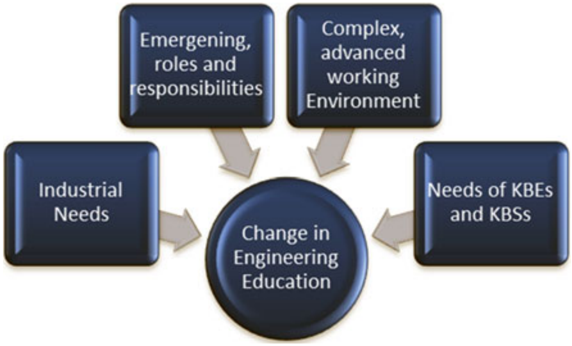


**Fig. 2.1** The model-of-four-driving-forces for focus on engineering skills (eng-skills-MoFDF)

graduate attributes (Kirkpatrick 2011; Rabl and Hillmer 2012; Patil and Codner 2008; Zaharim et al. 2010; Spinks et al. 2006) mainly in soft skills such as communication skills, leadership, social and ethical skills. Nowadays, industrial bodies are looking for graduates who are equipped not only with technical but also with many other soft skills (NSB 2007), and for some employers soft skills are even more valuable and appreciated (Khair et al. 2013).

The reason behind this gap is the imbalanced focus of the engineering education on teaching engineering knowledge and technical skills at the expense of enforcing soft skills in the students (Childs and Gibson 2010). As a response, the US and Australian engineering education systems have shifted over the last 15 years towards an outcome-based approach to produce graduates with necessary skills for the industry market (Walther and Radcliffe 2007).

The gap between education and practice of engineering can widen in the future (NAE 2005). Especially in the GCC and Middle East, the gap is higher due to the rapid development and growth dynamics in the market and industry that have not been coupled with adequate educational advancements to keep an alignment between both. Hence, prompt actions need to be taken to advance the engineering education system, to better prepare the graduates for practice, and to satisfy the need of industry.

### *2.2.2 Driver 2: The Ever-Evolving Emergences, Roles, and Responsibilities of the Engineering Profession*

It is argued that the definition of engineering should be expanded to cover the emerging trends and roles of modern and future engineering (Tech 2011). Felder (1998) indicates that an engineer with technical knowledge only is no longer sufficient to solve the new complex and interdisciplinary problems. Twenty-first-century engineers are expected to invent solutions to "grand challenges" which are global in nature, such as poverty, health, environmental concerns, housing, food preservation, and political instability (Klein-gardner 2011; NSB

2007; King 2008). Furthermore, they need to understand global markets and business practices; understand global ethical, safety, and security standards; have cultural, social, and political awareness (Chang et al. 2009; Patil and Codner 2008; Klein-gardner 2011), and pay attention to economic, environmental, political, and social constrains while developing solutions for their future problems (Calfee 2009; Mishra 2010). Chang et al. (2009) have stressed that global engineers "*need to become more aware of and responsible about their societal problems, investigate them*, *and put innovative solutions*".

Engineering/STEM graduates of twenty-first century are not only demanded for technical and scientific careers, but also started to play essential roles in non-traditional fields such as business, finance, management, policy, and social studies.

### *2.2.3 Driver 3: Adapting to Highly Advanced and Complex Working Environment*

There is a huge international expansion of today's market, companies, and supply chains and their tendency to work on projects with collaborations from different countries (Mishra 2010; Parkinson 2009). In this open world of advanced technology, open trade, and multinational companies, engineering graduates are expected to have global competence (Parkinson 2009) and to be able to solve various types of problems under various constrains and in different circumstances (Kastenberg et al. 2006). Such working environments involve team members of various nationalities, cultures, and languages. (Mishra 2010; Duderstadt 2010; Klein-gardner 2011) Consequently for these fairs and projects to be successful, they require their members to have not only good technical but also soft skills, such as communication and teamwork skills (Mishra 2010).

Dealing with advanced technology and complex systems in engineering problems requires highly interdisciplinary engineering teams who have a broad mental span instead of narrow practice within traditional disciplines (Duderstadt 2010; NAE 2004; Rabl and Hillmer 2012). Engineering graduates will need to efficiently interact and collaborate with other engineers including graduate of emerging engineering disciplines such as bio and genetic engineering, medical engineering, financial engineering, nanoengineering, and ecoengineering. (Agogino 2005; NSB 2007) in addition to experts from non-engineering professions (NAE 2004; Educate to Innovate 2009).

Alongside the change in the market, engineering curricula have to change and incorporate subjects of globalization, multiplicity, world cultures and languages, communication, leadership, and ethics, environmental regulations, and sustainable approaches in design as core elements (Jamieson et al. 2009; Mishra 2010). Some well-known universities, such as Purdue, have developed their engineering programme into a "global engineering programme" with the goals of developing and improving the students' soft skills allowing their graduates to standout in culturally diverse teams (Jamieson et al. 2009).

### 2.2.4 Driver 4: Compliance with the Generic Needs of KBSs and iKBEs

One major contributor to the transformative shift of considerations of needed skills of engineering graduates is the requirements of knowledge-based societies (KBS) and economies (iKBE) (Male and Chapman 2005). Tryggvason and Apelian (2006) refer to the emergence of engineers' roles during the last two centuries as follows: 1—the professional engineer: nineteenth and first half of twentieth century; 2—the scientific engineer: second half of the twentieth century; and 3—the entrepreneurial engineer: twenty-first century. Entrepreneurial engineers are engines of innovations that are driving high value-adding economic growth of twenty-first-century Innovation and Knowledge Based Economies and nations. iKBE or KBS generic skills and competencies such as communication, lifelong learning, and adaptability have also become frequently cited in the literature on required skills and attributes for engineers (NAE 2004, 2005; RAE 2007). It is worth mentioning that certain core engineering skills such as problem-solving and analytical thinking became essential even for those who would study and work in non-engineering disciplines; such core engineering skills are becoming frequently cited as necessary generic skills for the workforce and citizens of KBSs and iKBEs.

### 2.2.5 Literature Review Methodology

This is a literature review aimed at identifying related studies on competencies and skills needed of twenty-first-century engineers. A number of relevant keywords were utilized in the search of related literature in Google Scholar, as well as research databases such as ScienceDirect and IEEE Explore. Keywords were included, for example "future engineers", "engineers of 2020", "engineering employability skills and attributes", "graduates' attributes", "twenty-first-century skills", "global engineer", "generic skills", and "graduate employability".

The focus of the scan was on identification of key current and futures engineers' skills set, employability skills, skills set requirements of citizens of iKBEs and KBSs, different research methodologies that have been followed, and any developed frameworks and global approaches utilized to integrate these skills in education and training.

More than 500 studies, reports, and research papers were found. After initial filtering, about 190 of the found documents have been selected for full review. The reviewed articles included about 150 research papers and 40 reports. The majority of studies and reports had a specific national context, such as

- USA-focused studies (27 documents): (Casner-Lotto and Barrington 2006; Chang et al. 2009; Co-sponsors et al. 2008; Danielson 2011; Duderstadt 2011; Finegold and Notabartolo 2010; HRA 2013; Hundley 2012; IFEES n.d. 2012; Jamieson et al. 2009; Knight 2012; Mena et al. 2012; Michigan 2009; NAE 2004, 2005, 2011; NSB 2007; P21 2008; Palmer et al. 2011; Parkinson 2009; Patil and Codner 2008; Rajala 2012; SCANS 1991; Shuman et al. 2000a; Terenzini and Lattuca 2011; Tippins and Hilton 2010),
- Australia-focused studies (14 documents): (ACER 2002; Bowman 2010; Dawe 2002; DEST 2006, 2007; Gibb 2004; Kerr 2010; SA Male 2010a; MSA 2012; NCVER 2003; Nguyen 1998; Rabl and Hillmer 2012; RAY Townsend and Waterhouse 2008; Wheelahan et al. 2011),
- UK-focused studies (11 documents): (Allan and Chisholm 2009; CBI 2007, 2009, 2012; Edinburgh 2012; IEA 2009; Markes 2006; Martin et al. 2008; PyeTait 2011; Spinks et al. 2006; UKCES 2009),
- Malaysia-focused studies (6 documents): (NHEAP 2007; Nor et al. 2008; UNESCO 2012; Zaharim et al. 2009; Zaharim et al. 2010),
- Canada-focused studies (3 documents): (Canada 2000; Chan and Fishbein 2009; NESP 2010),
- Hong Kong-focused studies (2 documents): (Fung et al. 2006; Noakes 2004),
- India-focused studies (2 documents): (Mishra 2010; Saravanan 2006),
- Ireland-focused studies (2 documents): (Childs and Gibson 2010; Statz 2003),
- Scotland [1 study (Hounsell 2011)],
- Netherlands [1 study (REFLEX 2007)]
- Japan [1 study (Nguyen et al. 2005)],
- Indonesia [1 study (UNESCO 2012)],
- Philippine [1 study (Llanes 2008)],
- Singapore [1 study (WDA 2009)], and
- Thailand [1 study (Sunthonkanokpong 2011)].

Some of the other reviewed studies have had an international or continental scope (Continental 2006; ERT 1995; SHAH 2009). No studies were found from the Gulf Corporation Council (GCC), Middle East, or North Africa.

All reported skills in the reviewed studies have been synthesized. A content analysis approach was utilized for systematically categorizing them and also for generating a generic definition for each category. Content analysis is an observational research technique that can be used to systematically evaluate any content in order to identify the scripts in terms of various categories (Li and Cavusgil 1995; Kolbe and Burnett 1991; Holsti 1969). Definitions, terminologies, and types of skills and attributes were synthesized, and a relevant conceptual framework has been developed.

## 2.3 Engineering Education Accreditation Systems and Engineering Competencies

Undergraduate education plays a significant role in the development of engineering and employability skills of graduates. It shapes and refines these skills through students' involvement in various projects, assignments, lectures, etc. Higher education institutions usually aim to satisfy the accreditation requirement of different national and international accreditation bodies to achieve and prove high-quality educations experiences for its students. Over the last 2 decades, and in the light of recognizing the importance of students' learning outcome, a dramatic shift in the accreditation requirements has occurred from being input-oriented to output-oriented criteria. Thus, the focus is now on what the students are competent in rather than on what resources have been employed in teaching them. Satisfying these criteria and being accredited guarantee that the students of such programmes attain certain outcomes including a set of soft skills. In this study, the review of various engineering education accreditation systems has been conducted and a set of competencies required were extracted in the process of developing competency needs of twenty-first-century engineers. Engineering accreditation systems from USA, UK, Europe, Australia, Japan, Singapore, and Malaysia were reviewed. Appendix A provides details on the engineering attributes these systems require.

## 2.4 Synthesis of Global Set of Skills

The synthesis of a global set of skills of twenty-first-century engineers has been achieved in four stages:

1. Identifications of various terminologies in regard to skills or competencies,
2. Skills extraction from the literature on skills and competencies (engineering and non-engineering),
3. Model generation, and
4. Counting and quantifying.

Further details on each stage are provided in the next subsections.

### *2.4.1 Definitions: Skills, Attributes, Competencies, and Others*

#### 2.4.1.1 Generic Literature (Non-engineering)

There has been a wide range of terminologies and definitions that have been utilized to describe and define the different terms of skills and attributes. The term "skills" is normally utilized to refer to the ability of performing a task. The term "attribute" refers to a characteristic or feature of something and it might be part of the personality nature or might be developed through life experience. Both skills and attributes constitute key elements for employability. They both refer to the ability to apply content knowledge in a practical way in order to accomplish a mission or a task. Knowledge is defined as the interaction between the capacity (intelligence) and opportunity (situation) to learn something, and it includes theory and concepts. The term ability refers to basic competence (skills, knowledge, and attitudes). The term competence has also been defined by the Organization for Economic Cooperation Development (OECD) as "*the ability to successfully meet complex demands in a particular context*" (OECD 2002). It is indicated that the development of competence issue is influenced by a number of factors that are as follows: (a) ability, (b) knowledge, (c) understanding, (d) skill, (e) action, (f) experience, and (g) motivation. The OECD classifies competencies into the following: 1—"key competencies" and 2—"specific domain competencies".

Key competencies are defined considering those "important across multiple areas of life and contribute to an overall successful life and a well-functioning society" (OECD 2002), while specific domain competencies are those which "do not apply across multiple areas of life and are not necessary for everyone or are irrelevant to the betterment of individual and societal life" (OECD 2002). The term "key competencies" coined by the OECD is similarly referred in other literature by the term "generic skills" or "generic competencies" (Hager and Holland 2006; Male and Chapman 2005). Internationally, generic skills are known by a number of different terms from one country to other (NCVER 2003; UNESCO 2012) such as basic skills, necessary skills, and workplace know-how (USA). Generic skills can be referred as core skills, key skills, common skills (UK); key competencies, employability skills, generic skills (Australia); employability skills (Canada); critical enabling skills (Singapore); transferable skills (France); key qualifications (Germany); transdisciplinary goals (Switzerland); and essential skills (New Zealand).

According to Hager and Holland (2006), the term "generic skills" has been widely utilized recently across education systems for the adjustment of outcomes of graduates, where they are often called "graduate attributes" or "graduate qualities". The term "generic skills" refers to a wide range of qualities and capabilities, which can be applied in different aspects of life, work, and academia. Hence, generic skills include both graduate skills (and graduate attributes) and employability skills. Graduate attributes are defined as "*the skills, knowledge, and abilities of university graduates, beyond disciplinary content knowledge, which are applicable to a range of contexts*" (Barrie 2007). Clearly, graduate attributes are more than just skills and competencies for employment; they are life skills as well. Employability skills are sometimes mapped into a number of terms such as key skills, core skills, life skills, generic skills, essential skills, key competencies, enterprise skills, necessary skills, and transferable skills (DEST 2007). Employability skills are the bridge between academia and work and have been defined in literature as "*a set of achievements—skills, understandings, and personal attributes—that make graduates more likely to* *gain employment and be successful in their chosen occupations, which benefits themselves, the workforce, the community, and the economy*" (Yorke and Knight 2006).

#### 2.4.1.2 Engineering Literature

Skills identified in the engineering context literature are normally divided into two categories: the "technical" or "hard" skills and "non-technical" or "soft" skills; both technical and non-technical are complementary skills for engineers (NAE 2004, 2005). The non-technical skills are considered important to deliver the technical skills in a proper way (NAE 2004, 2005). The non-technical skills are also called a variety of other different terms such as soft skills, twenty-first-century skills, professional skills, foundation skills, graduates' skills, functional skills, and graduate qualities (NCVER 2003). Engineering skills can be also divided into the global and the local.

### *2.4.2 Skills or Competencies*

In our understanding, attributes, skills, and competencies have been interchangeably utilized across the literature; however, we may refer to competency as a skill with higher level in performance. In this book, the terms will be used interchangeably unless otherwise explicitly stated.

### *2.4.3 Skills Extraction*

A synthesis of skills was performed taking into consideration two main dimensions:

- DIM1—Skills that are required for current and future engineering graduates (extracted from engineering-related literature) and
- DIM2—Generic graduate skills normally in a KBS or a iKBE context (extracted from general literature, not engineering related)

Dimension 1 focusing on engineering skills is coined with **engineering skills**, while Dimension 2 is coined with **general skills**. In this stage, the retrieved papers from the literature were reviewed and all the skills mentioned were extracted and tabulated under one of these two dimensions. The first list included skills from studies on future engineers, engineering graduates, global engineers attributes, and engineering accreditation systems; while the second list included skills from studies on employability, twenty-first-century, generic skills, and graduates' attributes. For each dimension, a list of about 200 skills has been extracted from the literature.

A total of 37 references have been utilized in synthesizing the list in the engineering skills dimension, while a total of 34 references have been utilized in synthesizing the list in the general skills dimension.

## 2.5 Global Competency Framework and Model Development

In our review of different set of literatures spanned over employability, graduate attributes, twenty-first-century skills, Innovation and Knowledge Based Economy competencies, engineering skills, etc., it was apparent that both engineering literature and non-engineering literature share global set of competencies that can be themed into couple of dimensions and categories. Content analysis led to categorize the skills found into a set of 22 items of global skills under 4 main dimensions.

1- **Dimension I—Core Knowledge and Practice**, which includes the following competencies: 1—science knowledge (math, physics, and science fundamentals); 2—disciplinary fundamentals, 3—interdisciplinary fundamentals, 4—multidisciplinary knowledge, 5—practical experience, and 6—ICT skills.
2- **Dimension II—Cognition, Mental, and Thinking**, which includes the following competencies: 1—lifelong learning, 2—problem-solving, 3—decision-making, 4—analytical thinking, 5—systems thinking, 6—critical thinking, 7—creative and Innovation, and 8—design.
3- **Dimension III—Professional and Interpersonal**, which includes the following competencies: 1—professionalism, 2—ethics and responsibility, 3—adaptability, 4—communications, 5—teamwork, and 6—foreign languages.
4- **Dimension IV—Business and Management**, which includes the following competencies: management, leadership, and entrepreneurship.

### *2.5.1 The Pyramid of Global Competencies*

The four dimensions described earlier in the previous subsection are categorized into a pyramid model composed of four main levels: 1—generic, 2—domain specific, 3—subdomain specific, and 4—functional specific; see Fig. 2.2.

**Level 1—Generic**: The Dimensions II, III, and IV are global for twenty-first-century human talent; they can be needed in most disciplines and professions, and they are also considered as competencies for life, personal, and interpersonal relations. Dimension I in an abstract manner is generically applicable to all professions, but it functions as a differentiating dimension. The type of competencies in Dimension I will be different depending on the domain. This is what we call Level 1 in the competencies pyramid model shown in Fig. 2.2.

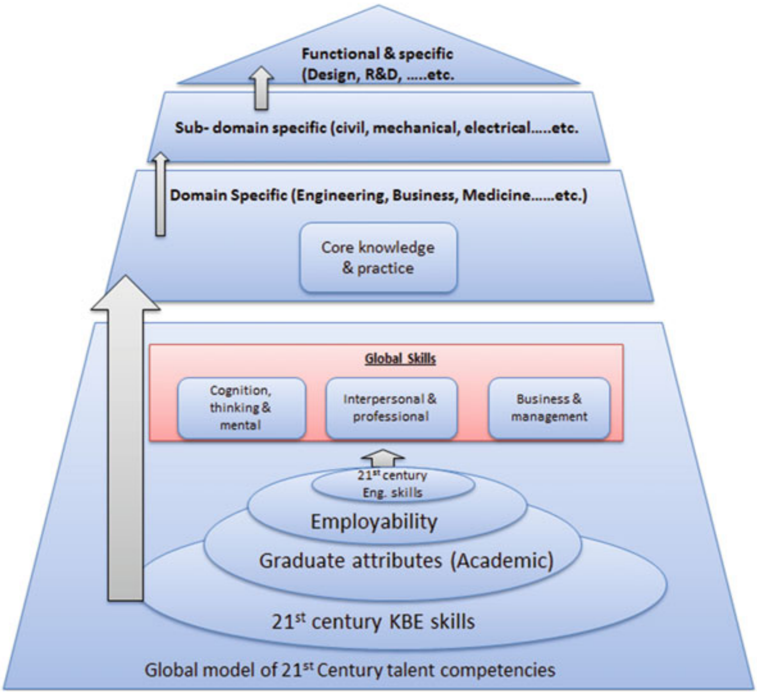


**Fig. 2.2** Ontological conceptual framework of the relation among skills (from generic to specific)

**Level 2—Domain Specific**: Dimension I is a differentiating set of competencies depending on the discipline. For instance, in engineering the following competencies will be applicable for Dimension I: 1—sciences knowledge (math, physics, and science fundamentals), 2—disciplinary engineering fundamentals, 3—interdisciplinary engineering fundamentals, 4—multidisciplinary knowledge, 5—practical skills, and 6—ICT skills. In another field such as business, for instance, Dimension I competencies will be as follows: 1—sciences knowledge (math, physics, and science fundamentals), 2—disciplinary business fundamentals, 3—interdisciplinary business fundamentals, 4—multidisciplinary knowledge, 5—practical skills, and 6—ICT skills. Taking a discipline in engineering (Eng) and in business (Buis.) such as electrical engineering (Eng.) and accounting (Buis.), Dimension I competencies will be differentiating in these sets. For instance, practical skills in electrical engineering will be to a significant extent different from practical skills in accounting; science knowledge in engineering will be to a significant extent different from math and sciences knowledge in accounting. Electrical engineers will need to know interdisciplinary knowledge of other engineering disciplines such as mechanical and computer engineering, while accountants will need to know interdisciplinary knowledge of other business disciplines such as management or information systems. Electrical engineers will need to know apart from conventional software such as MS word, knowledge about engineering software tools such as MATLAB or CAD design, while accountants similarly need to know about MS word, but also other specific domain software systems for accounting.

**Level 3—SubDomain Specific**: Similarly, Dimension I competencies will get further differentiation as we move from a domain specific (e.g. engineering or business) into a subdomain specific (e.g. electrical engineering or mechanical engineering in the engineering domain, or accountant or information systems in the business domain).

**Level 4—Functional Specific**: This level will differentiate the competencies of Dimension 1 depending on the employability function. For instance, engineers in R&D will need more in-depth knowledge of math and science fundamentals, and disciplinary engineering knowledge, than engineers in design function. Engineers in design function will need more practical skills, interdisciplinary engineering knowledge, and multidisciplinary knowledge than engineers in R&D functions.

Overall, Dimensions II, III, and IV form a global space of competencies that operate in a sphere of a domain or subdomain, and are also differentiated depending on function. The relationship among the four dimensions is represented visually with a 3D space composed of Dimensions II, III, and IV, which are professional and interpersonal, cognition and thinking, and business and management. Dimension I (the differentiating dimension) is represented by a sphere in the 3D global competencies space; this is shown in Fig. 2.3.

The relationship among the different terminologies and concepts of skills reviewed in various literature has been systematically modelled and are shown in an ontological framework in Fig. 2.2. The analysis has shown that all of the 22 skills

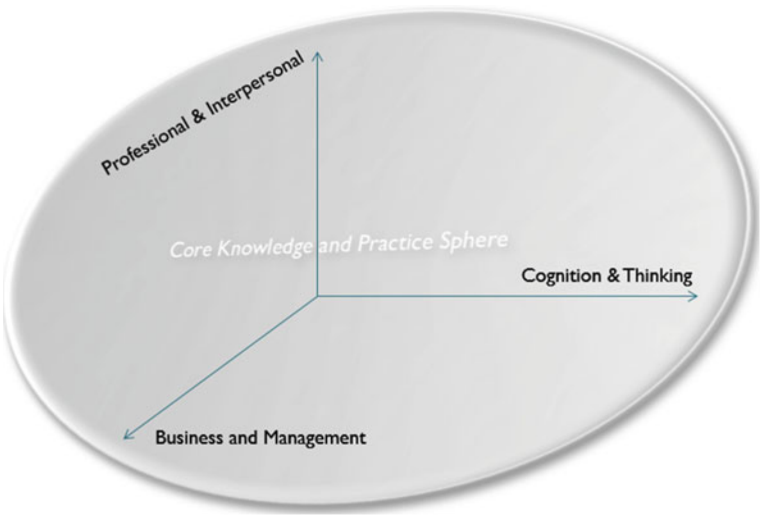


**Fig. 2.3** Twenty-first-century talent competencies

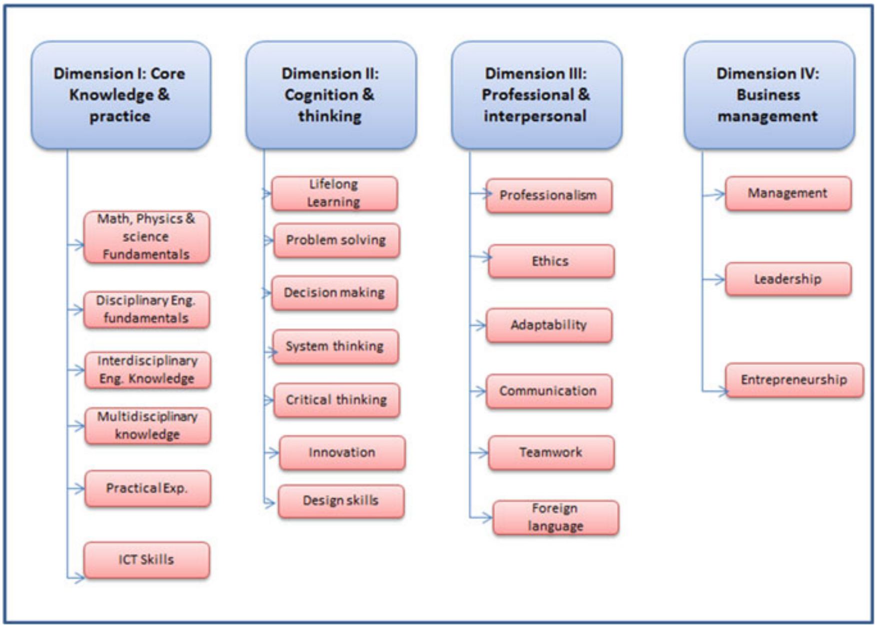


**Fig. 2.4** The global set of twenty-first-century skills

are common between the two aimed dimensions, but topological differences in terms of emphasis have arisen; this will be highlighted in further details in this section. The global set of 22 skills are further defined and detailed later in Appendix B; Fig. 2.4 shows the developed model.

### *2.5.2 Counting and Quantifying*

At this final stage, the total number of papers for each set of skills was calculated as a percentage of the total number of references for each of the two domains. This has been done to quantify the emphasis on each set of skill at each of the **engineering skills** and the **general skills** (or what we call the twenty-first-century talent competencies) literatures. Further comparisons, implications, and elaborations are given in the following section, see Fig. 2.4.

### *2.5.3 Discussion*

The review indicated that the most highly emphasized 6 skills in the literature for the **engineering skills** are as follows: 1—communication skills, 2—business and

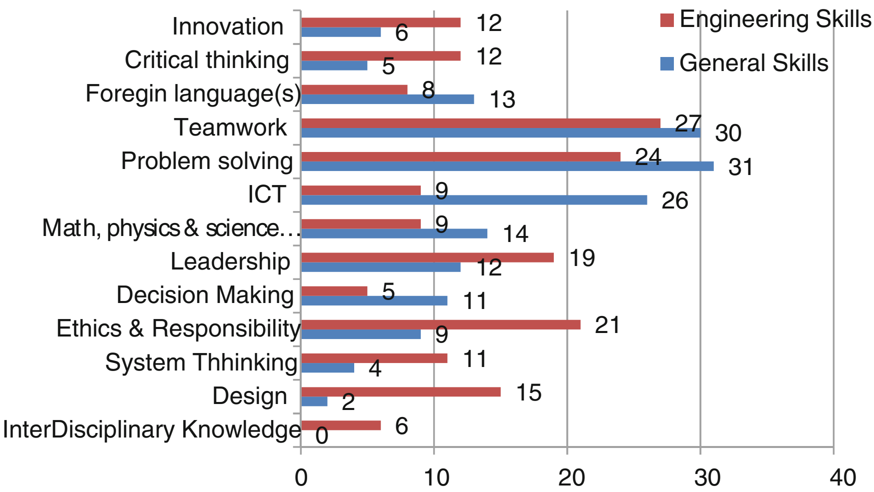


**Fig. 2.5** Skill sets that have more difference in emphasis comparing both general skills and engineering skills literatures

management 3—teamwork skills, 4—problem-solving, 5—lifelong learning, and 6—ethics and responsibility. While for the **general skills** there were 1—communication skills, 2—problem-solving, 3—teamwork, 4—ICT experience, and 5—business and management. Significant gap of emphasis between the ENGD and the **general skills** is found in 12 skills. A significant difference in emphasis (i.e. $\geq 15\,\%$) was found for 12 of the skills illustrated in Fig. 2.5. The greatest difference in emphasis was noted for ICT skills, design, ethics and responsibility, problem-solving, and multidisciplinary knowledge when comparing the generic to the engineering skills literature.

The greater emphasis on system design and thinking skills in engineering references could be attributed to the nature of the profession itself, which requires more of these skills as compared to other professions. Practical experience being more emphasized for engineering indicates the greater need for engineering graduates to be prepared for the huge complexity of the twenty-first-century working environment of engineers. Surprisingly, there is greater emphasis on ICT experience and problem-solving skills as generic skills rather than engineering skills. However, it could be hypothesized that engineering graduates are more familiar with the new technology as compared to graduates from other disciplines, such as medicine and business, requiring less emphasis in the literature. The same could apply for decision-making skills because the engineering profession involves decision-making by its nature (mainly technical, but many times non-technical too). Also, engineers during their studies have to take numerous decisions while working on projects, engineering design courses, or even complex open-ended problem-solving. The higher emphasis on ethics and responsibility of engineers shows the greater than ever need to integrate ethics into engineering education.

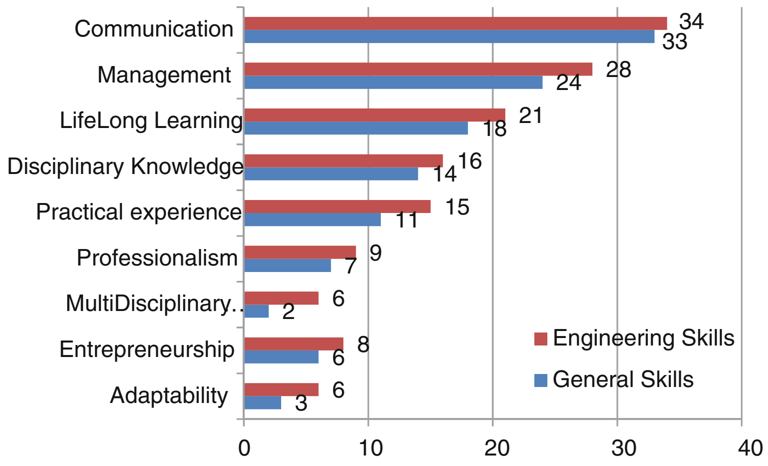


**Fig. 2.6** Skill sets that have less difference in emphasis among general skills and engineering skills literatures

Ethics are vital to be considered while designing, deploying, and servicing engineering solutions. Foreign language skills have been closely emphasized as both engineering and generic skills, which can reflect the global multinational multicultural working environment of today's world. Communications skills were among the most highly emphasized set of skills from literatures. Adding to that the high emphasis on teamwork, this can be attributed to the team-based practice of many professions. Being a lifelong learner is critical not only for engineers but also for other disciplines in the world of rapidly expanding knowledge (see Fig. 2.6).

## 2.6 Systemic Model of Competency Development

### *2.6.1 Ontological Relations and Mechanics*

In this section, a systemic framework for the ontological relations among the different definitions previously is developed. The main aim is to clarify the confusion among the different concepts and definitions utilized, and also to sketch a clearer visual model on the mechanistic relationship of skills development in two main spaces: 1—the education and training system, and 2—the workplace and/or authentic real-life contexts. From the previous definitions outlined earlier, one can conclude that attaining a competency passes through the following process that is spanned over two spaces: **Space 1**—the education and/or training system: *1—help to acquire a preliminary content knowledge either by training or through an education system; 2—facilitate blending of the knowledge with an intrinsic attribute and charter; 3—provide opportunities to apply the blended knowledge in an* *application context. These efforts will help to develop preliminary skills (can be called a graduate attribute), which can lead to a higher order intrinsic attributes or character.* **Space 2**—the workplace and/or authentic real-life context: *the context implies that the conditions are larger in space, require inputs from more than one discipline and require a lengthier planning and development period than those dealt with in Space 1. Therefore, the system should help to 1—acquire a needed contextual content knowledge; 2—facilitate blending of this knowledge with a higher order intrinsic attribute and charter; 3—provide exposure and opportunities to apply the knowledge on complexity in one or multiple application contexts, which can develop a higher order skill, or a competency, and would lead to a higher order intrinsic attribute or character.* The process in the second space might require an iterative phase with the first space that is iterating back to the fundamental education system to understand the recent developments in the subject area or to sharpen the skills to a higher degree. In either case, iteration becomes the key to prepare the skills to tackle the challenges of a iKBE.

### *2.6.2 Hypothetical Implications of the Model*

The sketched systemic model of competency development shown in Fig. 2.7 may lead to a number of hypothetical implications. These hypotheses govern the relationship and reciprocal continuity between the two main spaces a skilled human resource in a iKBE goes through.

**Hypothetical Implication 1—Continuity of Content Knowledge between Spaces**: *Complete distinction of content knowledge between Space 1 and Space 2 may result in delay or lower order of competency development; it may even require iteration through a new education/training system. Hence, educational/training systems should align their provisioned content knowledge with the needs of the workplace and real-life contexts their graduates are expected to function.*

**Hypothetical Implication 2—Continuity of Contextual Application**: *Higher resemblance of contextual application in Spaces 1 and 2 would lead to higher alignment in the development of attributes, skills, and competencies. Hence, educational/training systems should align the context by which their content knowledge is provision to become resemblance (as far as possible) to those contexts normally faced in the workplace and real-life situations their graduates are expected to function.*

**Hypothetical Implication 3—Emphasize on Application of Content Knowledge in Space 1**: *Traditional education systems tend to emphasize heavily on content knowledge provision, paying less attention to importance of applications for skills development. Theories, such as constructivism and experiential learning, in the learning sciences criticize such approaches, and emphasize the importance of*

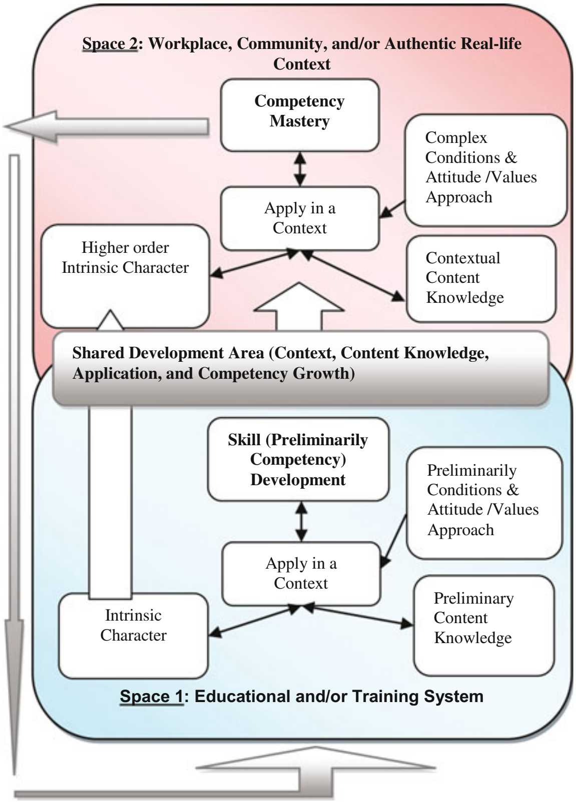


**Fig. 2.7** Semantic systemic model of mechanistic and ontological relationships between content knowledge, skills, attributes, and competencies

*applications for meaningful learning and skills attainment. Hence, educational/training systems that are heavily theory oriented with lack of experiential and active learning approaches for content knowledge applications may lead to poor development of graduate attributes needed for the workplace. Having modelled the dynamics and systematic development of competencies, the next subsection provides a view of needed competencies of twenty-first-century engineers in iKBEs and KBSs.*

The model implies several theoretical assertions for education systems that are effective and connected to the workplace and twenty-first-century graduates. In the next section, we provide a synthesis of recommendations collected from stakeholders and from the literature on improving the engineering education system to meet twenty-first-century requirements.

## 2.7 Stakeholders and Global Literature Recommendations for Twenty-First-Century Engineering Education for iKBE

Throughout this book's development, a significant number of recommendations have been attained and found through one of the following roots:

- Emerged from involved stakeholders in the study (industry: managers, trainers, HR, and practicing engineers; academia: faculty and senior students) and
- Synthesized from the reviewed literature globally

These recommendations have been summarized and categorized in the subsections below. Those recommendations that emerged from stakeholders in Qatar are cited with QS as an acronym of Qatar stakeholders, and the rest are cited via the reference they have been found in.

### *2.7.1 Engineering Practice and Industry: Academia Linkage*

The theme of engineering practice in engineering curriculum and better linkage with industry was one of the main observed emphases of interviewed stakeholders. Interviewees recommended introducing interventions for equipping students with practical skills needed for employer in advance of graduations to enhance job productivity, to reduce training programs' duration in industry, and to enhance employability for non-nationals (QS). Furthermore, all groups called for increasing the proportion of practical training and internships, even beginning with freshman year (QS); to further enable this, some have recommended developing a section or organizational structure in large companies dedicated for internships and industry–academia linkage (QS). Similarly, faculty reported that the absence of such effective structure on the academia side is one of the major barriers of enhancing industry–academia linkages. Several interviewees called to host instructors from industry in engineering courses and to include more feedback from industry in curriculum design (QS); similar calls have been recommended in international studies of Nor et al. (2008) and RAE (2007).

### *2.7.2 Innovation, Design, and Entrepreneurship*

The theme of innovation, design, and entrepreneurship has been one of the other emerging focuses of stakeholders' recommendations, similarly with recent trends internationally indeed. Several stakeholders recommend establishing structured programs that encourage innovation and design skills in order to help to have iKBE industries [QS]. Design-based engineering education is increasingly embraced as a new philosophy; one of the most influential policy reports by the National Academy of Engineering (USA) recommend to include hands-on design projects from freshman year and in all professional years (NAE 2005). Furthermore, capstone designs were strongly recommended to be derived from real-world and industrial problems (NAE 2005). More emphasis on entrepreneurship and technology transfer in engineering education was highly recommended by interviewees as a major mean of transferring innovations in design into added value (whether economic or social) outcomes (QS).

### *2.7.3 Pedagogies and Engineering Education Research*

Engineering education research was one of the themes that was highly recommended by stakeholders from all targeted groups. Focusing on design- and project-based approaches with less written exams, in particular in junior and senior engineering education years, was highly recommended by interviewees (QS). Many calls encourage faculty to move from traditional teaching into more proactive approaches such as problem-based learning and practical learning (Nor et al. 2008). National Academy of Engineering (USA) recommend that engineering education institutions should encourage pedagogical research among its faculty as valued and rewarded activity aiming to understand students' learning and develop best methodologies of teaching (NAE 2005).

### *2.7.4 Curriculum, Training, and Programmes*

Engineering education programs as a theme was highly emphasized by interviewees for better enhancement. Engineering education curriculum (including initiating new programmes/courses) should be designed in an adaptive manner emphasizing in particular on management and leadership development in engineering education curriculum so that it can cope with future needs and trends of the country flexibly [QS] introducing requirements on continuous education for professional engineers to mandate frequent update of knowledge and skills after graduation and deployment in the workplace [QS]. Once new curricula or educational strategies have been implemented, continuous monitoring and reflection are strongly encouraged (Shuman et al. 2000b).

### 2.7.5 *Engineering Talent and Competency Development*

Engineering skills and competencies were highly demanded by stakeholders for better readiness to workplace. Competencies development as a well-rounded approach for enabling development of soft skills for engineering students using curricular and extra-curricular approaches was highly emphasized. (QS) (Bourn and Neal 2008). Making orientations to introduce all the majors to ensure students chose the major/career that suits them was one of the approaches recommended (QS). Developing an engineering career service in the university to assist in employability matters of fresh graduate engineers was also highlighted [QS].

## 2.8 The Interrelation Between Twenty-First-Century Engineering Competencies and Leadership Attributes

Throughout the review, a correlation has been identified by the global set of twenty-first-century iKBE attributes and leadership attributes. Leadership most of the times is summed into one term which is "*leadership*"; however, a deeper look on the literature of leadership space reveals a significant amount of attributes. In this book, a more critical view of leadership attributes and models is provided and has been interlinked with the global literature on twenty-first-century iKBE skills. For instance, twenty-first-century skills such as communications, teamwork, and problem-solving are core leadership attributes that are found in almost any leadership models. Furthermore, the engineering education community has been progressively developing various programmes and interventions in the engineering education curricula in order to equip future engineering graduates with leadership skills. Further details on this subject are provided in the next chapter.

## 2.9 Conclusions

This chapter provided a comprehensive literature review on the ever-evolving subject of needs of twenty-first-century engineers. The review spans over significant number of studies worldwide, and no relevant investigation has been detected in the Middle East or the GCC area. Synthesis of the literature led to development of a four-dimensional model of engineering skills that consist totally of 22 competencies. The model has been utilized in subsequent stages of the investigation in order to solicit perspectives of stakeholders in any country of investigation, for current and emergent needs of engineering talent attributes. Furthermore, other systematic models representing global twenty-first-century engineering talent skills and competency development models have been developed and described in detail.

Synthesis of the literature on needs of engineering education system for twenty-first-century engineering graduates has been provided. The next chapter provides further details on leadership and engineering.

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