Professional Roles and Employability of Future Engineers

ABSTRACT

Although there is high degree of agreement on the importance of transversal skills for engineers, employers observe a significant gap between expectations and reality. This paper discusses the need for the development of a framework of professional roles for future engineers and the implementation of dedicated skills education in engineering curricula to train students for this role. Based on an extensive literature study an overview is given of previous research on this topic. The paper also outlines the next steps that will be taken by the authors as part of a European project PREFER to develop and implement these roles in engineering education.

Conference Key Areas: Continuing Engineering Education and Lifelong Learning; Skills and Engineering Education; Curriculum Development

Keywords: Labour market entry; Transversal skills; Professional roles; Skills mismatch

INTRODUCTION

The European project PREFER (Professional Roles and Employability of Future Engineers) aims to reduce the skills mismatch in the field of engineering. A large survey among 467 Flemish engineers who graduated between 2014-2016, indicated that 22% of the respondents were no longer working with their first employer. Almost half of these graduates left because the job did not meet their expectations or was below the assumed level [1]. This mismatch brings along considerable training costs for companies. Moreover, companies have trouble finding the right engineers for vacant positions. In Belgium, both the number of vacancies and the number of job seekers is increasing [2]. Managers of human resources departments report that fresh engineering graduates frequently display (1) a lack of transversal skills required by the labour market and (2) a lack of self-awareness of their own strengths and weaknesses and of who they are as an engineer.

The objectives of the PREFER project are threefold. First, we aim to construct a Professional Roles Framework. This framework will describe the different roles engineers can take on at the beginning of their career, independently of the engineering discipline (e.g. electrical, mechanical, chemical ...). Each role will be characterized by an associated set of transversal skills. Thereafter, a Test System will be developed in order to (1) increase engineering students' awareness of the multitude of professional roles in engineering and (2) to make them reflect on their own engineering identity and their interests, strengths and weaknesses. Thirdly, we will explore how to implement these innovative tools in the engineering curriculum by running a number of pilots in the participating universities.

In order to realize the PREFER objectives, a well-balanced consortium was built with both universities (University of Leuven [Belgium], Delft University of Technology [The Netherlands] and Dublin Institute of Technology [Ireland]) and companies (Engie, Siemens and ESB) involved. In order to develop reliable and valid test material, an experienced test development partner (BDO) is a member of the project team. To establish a stable connection with the engineering labour market, the three national engineering federations in Belgium, The Netherlands and Ireland were brought on board (IE-net, KIvI, Engineers Ireland). These federations play an essential role in connecting higher education institutions with a large number of employers that hire engineers. Validation in a wider European network of universities and companies will be tackled by respectively SEFI and FEANI.

1 PROFESSIONAL ROLES IN THE FIELD OF ENGINEERING

1.1 Problem statement

The McKinsey 'Education to Employment survey [3], organised with more than 5,300 young people, 2,600 employers, and 700 education providers, shows that only 35% of the employers agree that new graduates are adequately prepared. Interestingly, for education providers, these percentages increase to 74%. Apparently, on the supply side, education institutions believe that they are equipping their students with the necessary skills and competences whereas employers, on the demand side, feel otherwise. This skills mismatch has become an important topic on the agenda of many policy makers. A focus on transversal skills (e.g. self-management, interpersonal skills, adaptability, communication skills, interpersonal skills …) is often put forward as important way to overcome this skills mismatch.

In the field of engineering education, interpersonal skills, teamwork, communication, and problem solving skills are most frequently identified as highly important by engineers [4-5]. As stipulated by Chan et al. [4], although there is high degree of agreement on the importance of these skills, employers observe a significant gap between expectations and reality (see also [6]).

Apart from the skills mismatch, a number of employers indicated that fresh engineering graduates are unable to identify their strengths and weaknesses during a job interview. It appears that fresh engineering graduates lack the introspective qualities to look at themselves and reflect about the question "*Who am I as a, for example, electrical engineer?*". Answering this question does not only entail a critical self-reflection on one's own thoughts and prior achievements, but also an articulation of one's future aspirations in the engineering profession. The latter aspect presumes a more detailed knowledge of the different professional roles that engineers fulfill in the labor market and which sets of competences are required for engineers working in different professional roles. For example, in the field of chemical engineering, an R&D engineer may require a completely different set of transversal skills compared to an engineer in a more commercial role.

1.2 Employability: Increasing self-awareness

Employability is often used as a container term without exact definition. In line with Yorke and Knight [7], we endorse three components of employability: (1) increased understanding of academic knowledge, (2) a set of generic skills appropriate to the workplace, and (3) personal attributes (e.g. enthusiasm, flexibility, self-reliance, aspiration, seizing opportunities). As pointed out by Creasy [8] improving employability skills "*requires students to record their achievements and to reflect on these*" (p. 18). The author showed that students find it difficult to articulate their employability skills and that they have problems with writing reflective reviews about themselves and their own assessment of their competencies.

Increasing self-awareness among engineering students requires a high level of metacognitive thinking and the ability to reflect at a higher order level about oneself as a future engineer. Improving metacognition includes helping learners to (1) be more aware of their own implicit beliefs and (2) build a broader sense of purpose behind their learning [9]. An important trigger to stimulate metacognition is by asking engineering students the right questions. For example, how do they picture themselves in their future engineering profession? Which skills have they mastered during project work or which qualities have they identified in themselves during a company visit?

1.3 Labour market entry for recently graduated engineers

As stated by Hofland et al. [10], there is a wide variety in career paths for graduated engineers. Going beyond the typical specialist versus management-dichotomy, this diversity is reflected both in terms of disciplinary wealth (e.g. electrical engineering, chemical engineering, civil engineering …) and the professional roles that engineers fulfil in a particular organisation (e.g. service engineer, technical_sales engineer, product engineer, process engineer …).

An important challenge of the PREFER project is to come up with an integrative framework wherein this multitude of engineering positions is summarized in a manageable and sensible way. However, it is not our intention to put forward a perfect classification model wherein each engineering position holds a unique place that is mutually exclusive. Instead, we argue in favour of a framework wherein engineering positions can be described in overlapping sections if they fit several professional roles.

A similar framework has already been designed for the field of medicine. The CanMEDS framework that identifies and describes the abilities physicians require to effectively meet the health care needs of the people they serve. These abilities are grouped thematically under seven roles [11].

2 PROFESSIONAL ROLES FRAMEWORK

In contrast to the plethora of studies focusing on the essential transversal skills in the field of engineering, research on the classification of the multitude of professional roles that fresh engineering graduates can take on in the labour market is scarce. It is often presumed that all engineering careers are homogenous and require the same balance of technical and transversal skills [12]. Other engineering careers than the stereotypical ‘engineering practitioner’, for example, researcher, consultant, technical-commercial representative, often receive less attention. In their study, Brunhaver and colleagues [12] discriminate between three engineering roles of a large sample of recently graduated engineers (N=543): manager (15%), engineering consultant (21%) and engineering practitioner (64%). Problem solving and analytical skills were deemed equally important in all three engineering roles. Interestingly, communication was rated as less important by engineering practitioners than by managers or consultants. Managing uncertainty, business knowledge, leadership and management skills were rated significantly higher in importantance by engineering managers. In educational practice, the authors argue in favour of ‘zero-based career planning’ wherein all engineering career orientations are considered valid.

In the following paragraphs we will describe the outcomes of the Rolling project at the Faculty of Engineering Technology of KU Leuven.

2.1 Business strategy model of Treacy and Wiersema

The business strategy model of Treacy and Wiersema [13] describes three strategic positions that companies can take in the value chain: (1) Operational Excellence (i.e. focus on maximizing efficiency by reducing costs while optimizing quality); (2) Product leadership (i.e. focus on cutting-edge research,innovation and market exploration of new client segments), and customer intimacy (i.e. focus on integration and service of client systems and customer satisfaction). According to the authors, a focus on one of these strategic positions enhances a company’s competitiveness in the market.

Interestingly, the business strategy model of Treacy and Wiersema can easily be translated into the engineering field. A large-scale analysis of more than 7,500 job vacancies in the field of engineering in the year 2014 [2], showed that each job vacancy could be classified in one of the three categories outlined above: Operational Excellence (46%), Customer Intimacy (30%), and Product Leadership (24%). Thus, 46% of the vacant engineering positions were related to maximizing efficiency and optimizing processes (irrespective of the engineering discipline).

2.2 First-year student survey

It should be noted that the original model of Treacy and Wiersema was only described in economic terminology and as a consequence, a translation tailored to the engineering domain was required. In the Rolling project, this translation was operationalized by means of three fictional engineering job vacancies, each reflecting one of the three roles). These three fictional vacancies were presented to a sample of 172 first-year engineering students. Students were asked to indicate which job vacancy they would prefer to apply for. In contrast with the outcomes of the large-scale job vacancy analysis, 58% of the first-year students expressed a preference for the Product Leadership role. Thus, there is a very clear discrepancy between the preferred type of jobs of first-year engineering students and the jobs that are available in this category (24%).

In a second stage of the survey, the first-year students were asked to rate their self-perceived mastery levels of the 13 faculty learning outcomes (e.g. problem solving, communication, critical reflection, entrepreneurship, for a comprehensive overview, see [10]). Interestingly, students with a preference for the Operational Excellence vacancy, expressed significantly higher levels of problem solving/analysis and operationalisation compared to the other students. Analogously, students with preference for the Customer Intimacy vacancy rated themselves significantly higher in communication and entrepreneurship. In sum, there seems to be evidence that students tend to be more interested in job vacancies for which they deem themselves to have the required competencies and consider themselves to be good at.

2.3 Company survey

The Treacy and Wiersema model was also presented to a large sample of companies employing engineers (N=121) [10]. 91% of the respondents indicated that they recognised the model in their own company. A small number of respondents (6%) indicated that they needed some adjustments to the model (for example, management was considered missing). In a next stage, respondents were asked to indicate to relative importance of each of the aforementioned learning outcomes for each role. For the Product Leadership role, design and development and specialized technical knowledge were considered to be the most important. For the operational excellence role, problem solving/analysis and operationalisation were deemed necessary skills. Finally, entrepreneurship and communication were labelled as important qualities in a Customer Intimacy role. It should be noted that this response pattern closely reflects the outcomes of the students' survey. For a more detailed overview, see [10].

2.4 Conclusion

The Treacy and Wiersema model seems to be a valuable framework to look at the variety of engineering positions. An important objective of the PREFER project is to fine-tune the model and to further tailor it to the engineering domain. Special focus will need to be spent on the specialist versus management dichotomy, a prevailing theme among many young engineers.

3 INTEGRATION INTO THE ENGINEERING CURRICULUM

In the following paragraphs of the paper, we will address how students' employability can be addressed in the engineering curriculum. An extensive search in engineering education literature as well as in literature on the initial path of recent engineering graduates was carried out. It was observed during this search that although higher engineering education institutes claim to prepare their students for their future career as an engineer, little evidence -if any- could be found of institutes making a distinction between the different roles a graduate will function in when working as an engineer, let alone that these institutes adapt their curricula in such a way that students can plot out a path to obtain skills pertinent to such a role.

Many of these preparations include the earlier defined transversal skills, next to internships such as detailed by Kamp and Verdegaal (2015) [14] and other activities such as company visits, guest lectures etc..

In order to limit the scope of this project, it was therefore decided to focus on a number of transversal skills. The selection was made in part based on the 4TU Centre of engineering education's vision on the future of engineering education [15]. The selected skills are:

- Entrepreneurial Skills
- Innovation Skills
- Communication Skills & Networking Skills
- Teamwork & Ways of Thinking
- Life Long Learning

In the sections below, good practices for each skill at Higher Engineering Education Institutes as found in literature are highlighted and critical notes from industry with regards to the lack of these skills are discussed.

3.1 Entrepreneurial Skills

Entrepreneurial skills are defined by Adeyemo as the ability to manage and create an enterprise by having vision and taking initiative and risk [16].

Nowadays, engineers working in business are asked to solve unstructured problems which are not solved with traditional decision analysis tools taught in the present curricula. In order to prepare students to tackle these problems, Garcia et al. introduced a realistic entrepreneurial case study in a graduate level Civil engineering course [17].

The idea of learning technical and entrepreneurial concepts while solving problems was the goal of another case study in a Western private university. In this instance , a case study and lab experiences were introduced in a core mechanical course. The case study comprised of a realistic case scenario where 12 engineering concepts (forces, stress, etc.) and 10 entrepreneurial concepts (business model, SWOT analysis, mission statement) were taught. Pre and post tests were carried out of students in order to understand if entrepreneurial skills could be implemented in core engineering courses without interfering with the technical skills and if a student's entrepreneurial self-efficacy (based on business confidence) changes with one case study. Results showed that students are able to increase their entrepreneurial skills without decreasing the learning of core engineering competencies and students reported self-efficacy improvement pre-to-post in just one case study [18].

Moreover, business and engineering are bridged by sales education in engineering programs. A department of industrial engineering supported by the university business school and industry partners provided a technical sales course introducing investment economic methods and theory. A pre-post survey of students assessed their interest and learning ability of sales skills. Results as published by Bumbluskaus et al. showed that the course enhanced students' sales skills and increased their desire to pursue a sales career [19].

The call from industry and governments for more entrepreneurial skills to be included is one heard globally. A report from various industry and governments stakeholders in the United Kingdom from 2008 already outlines the need and a framework for including entrepreneurial skills in higher education curricula [20]. In 2014 the G20 summit Brisbane released a final communique that called for the promotion of amongst others entrepreneurship and innovation skills [21].

3.2 Innovation Skills

Benjamin defined innovation as the creation of new and technically feasible ideas or the adaptation of others' ideas [22]. Innovation requires thinking out of the box and an open mind, using creativity and imagination but also the use of logic, analytics and planning. According to Kamp [15] students should be stimulated in innovation by going to new environments with new challenges, and new ways of thinking, such as going abroad for studies or undertaking a challenging design project in a completely different field.

The Engineering School of Los Andes University integrated a 2 semester course in the third year of the curriculum of System and Computing Engineering in order to improve teamwork and innovation skills. Students design and conceptualise a prototype. They present it in periodic written reports and oral presentation, and in a final presentation carried out in an engineering projects fair. During the project, students are advised by engineer-entrepreneurs. The best project has the opportunity to present at an Innovation Fair. Hernandez [23] indicated that students' perception of this course showed that they are aware of the importance of teamwork and innovation for their projects.

The National University in the United States developed a Global Design Methodology where higher education students design video games. This methodology was implemented in some courses and students learning outcomes were measured. For example, in the course of Critical Ethics, the highest outcome showed by students was creativity and imagination according to Kärkkäinen [24].

The Department of Computer Science and Information Engineering in the National Chung Cheng University of Taiwan created a capstone course which integrates training creativity. This training involves workshops of management techniques provided by managers, of work experiences delivered by alumni and of sustainability and globalisation shared by industry experts. According to Hsiung, the results of a project-based learning in combination with creativity training showed enhancement in students' creativity skills [25].

3.3 Communication Skills and Networking Skills

Communication for engineering universities is commonly based on oral and written technical skills [17]. In the curriculum of BSc Aerospace Engineering at Delft University of Technology, students have a technical writing course integrated in a Design & Construction project. Students indicated that the technical writing course is important to develop competences to perform the final design report of this course. In the second year, these students attend an oral presentation course incorporated in a System Design project. Students' opinion about this course was that it was very important for their personal skills development as stated by Saunders-Smits et al. [26].

However, communication is no longer restricted to oral presentation and written technical reports, but involves interpersonal communication such as listening, compromising, understanding others point-of-view and discussion with others as discussed by Kokkonen [27]. There are some interpersonal communication studies done in healthcare. In the United Kingdom, a review of the communication skills training in pre-registration nurse education identified empathy, self-awareness, interviewing-skills and critical thinking as the evaluated skills. The methods used were experimental methods, videos, lectures, group work, and drama workshops [28]. A study in the field of pharmacy in Finland showed improvement in communication competences by using practical training in real work situations, and feedback and communication between mentors and students [29]. Another study in Finland, but now with medical students in the second year used a three-experiment method (simulated patients, role-play and theatre education). Students' outcomes were awareness of interpersonal communication competence, knowledge of professional communication and patient-centeredness [30].

As Kokkonen, we view networking as an interpersonal communication skill, because networking is the ability of interconnect and create links among individuals through initiated and maintained communication. In other words, networking is the development and maintenance of interpersonal relationship by establishing contacts in different contexts, discussing with individuals, companies and enterprises, understanding their perspectives and listening skills [30].

It is essential to make students aware of the importance of networking and to enhance their networking competences which may open them to future opportunities such as finding the first job after graduation, maintaining the job and moving within the labour market. This importance of networking is proven in a study of alumni of Aerospace Engineering at Delft University of Technology [31].

Networking skills are commonly integrated outside of the normal curricula, such as in workshops on "How to Find a Mentor & Network for Career Success" performed at San Jose State University, where students were taught to pitch themselves and to create their networks. They had the opportunity to interact and ask questions to alumni [32].

Here it appears there is a mismatch between what universities teach as communication in the formal engineering curriculum and the needs of industry. Typical communication courses in engineering curricula involve a writing course and a presenting course but are aimed at producing work for a classroom setting. Studies by Donell et al. [33] show that there appears to be a disparity between the communication situations in the classroom and in the industry. Students are simply not able to switch when they enter a professional environment. In addition the contents of the communication courses may be too limited. Rarely do courses involve listening exercises, intercultural communication, or observing, interviewing and meeting skills. This does not mean students are not exposed to these skills in project-based education such as listed in [26] but they are not formally taught. Whether feedback is offered, depends on the individual tutor, rather than this happening in a structured fashion.

3.4 Teamwork & Ways of Thinking

As mentioned before, problems in engineering science are becoming more and more complex, requiring more than the problem-solving and decision analysis tools currently present in the curricula. The involvement of engineers in teams is the solution. We define teamwork as being based on collaboratively working in groups to achieve a goal. In teams, engineers are asked not just to think critically, i.e. to ask the right questions to formulate new directions to operate, but also to think interdisciplinarily, i.e. to collaborate and involve other engineering disciplines, humanities and social sciences [15].

In the last year of their BSc students of Aerospace Engineering at Delft University of Technology undertake a capstone project, called Design/Synthesis Exercise. In teams of 8 to 10 members , students are asked to play the role of System Engineer applying all their previously acquired engineering design skills. According to students' opinion, this project highly contributes to improving their ability to work in teams [26].

At the same university, Master students of Aerospace Engineering have the option to attend a Forensic Engineering course which uses real-life based learning. This course consists of lectures and practical exercises, ending with a practical exam where students should conduct an investigation and apply the forensic concepts learned during the course to find the cause of the accident. The results of this course show that students developed forensic knowledge, critical thinking skills, standard investigation methodology, hypothesis forming and interviewing [34].

At the University of South Australia, architecture and civil engineering undergraduates in a two-week elective course tackle a hand-on construction problem. The collaborative work and knowledge interaction between groups of 2 to 4 students of different disciplines, architecture and civil engineering students showed that students increase their multidisciplinary team work skills according to Tran [35].

Finally, at King Abdulaziz University, students enrolled in an introductory modelling course based on project-based and active learning, working in teams of 4 members with heterogeneous ability levels. The results show that students improved their ability to operate in multidisciplinary teams [36].

Working in teams is a vital skill in engineering. This was the primary reason it was added to the ABET criteria back in 2001 [37], after repeated calls from amongst other McMasters from the Boeing Company [37]. This is also embraced in the CDIO principle which was started due to calls from industry [38].

3.5 Ability for Life Long Learning

Another essential competency of today's engineer is life-long learning which is in our opinion continuous personal and professional development. In a world full of changes and uncertainty in career paths, "learning how to learn" should be the goal of engineering studies in order to prepare students for constant and continuous learning [15]. To engage lifelong learning skills, the Center for Engineering Learning and Teaching at the University of Washington, provide a course where students are taught to plan their studies, to assess and monitor their learning, independently find and use the information to solve problems and recognise their strengths and weaknesses [39].

Moreover, the ability of life-long learning was studied in the Faculty of Engineering at King Abdulaziz University with the introductory modelling course previously mentioned. The project was divided in 5 assignments and before each assignment further knowledge about the project was given, increasing the sense of continuous learning throughout the course. The results of students assessed by an entry and exit survey showed an increase for life-long learning [36].

At San Jose University, some courses (Introduction to Engineering and Aircraft or Spacecraft Design) in the engineering curriculum use design elements (discussion of engineering success, participation in activities of the society, self-learning process tests, design projects and assignments in life-long learning) which proved lifelong learning improvement [40].

Life Long Learning is becoming a key focus for many industries and governments alike. In order for a person to stay employed in their position they must be able to keep up with technological developments and changes in the way their industry carries out its business. An example is the retraining of the workforce at the Boeing Company for the production of the Boeing 787, Dreamliner. 2D Paper technical drawings were no longer used, only 3D computer models. The aircraft was to be manufactured primarily out of composites rather than aluminium. An intensive retraining schedule was created and successfully implemented. The awareness and ability of staff to retrain and acquire new knowledge were essential [41].

Other observations

When looking back at all the literature, a second observation can be made. Although many institutions eagerly implement transversal skills in their curricula with the aim to better prepare students for the labour market, little to no formal evaluation let alone measurement and analysis of the effectiveness of the implemented curriculum elements are carried out. A simple self-assessment of participants is often the only form of evaluation carried out. No longitudinal studies were found where students were followed in their years after graduation, or other forms of measuring the effectiveness of the skills education. This is an area that deserves serious attention in the opinion of the authors.

4 DISCUSSION

When examining the professional roles in the labour market of engineering graduates, a number of issues should be taken into account.

First, the size/type of company under scrutiny is an important consideration. Whereas some students will feel perfectly comfortable in the setting of a large company, other students might prefer the more familiar organizational culture of a small (<50 employees) or medium (<250 employees) enterprise. This aspect has fundamental consequences for the type of professional role chosen, given that larger companies typically have more specialised roles for one particular engineer whereas in smaller companies one engineer could be in charge for multiple professional roles (for example in combining a maintenance and technical-commercial role).

Second, in the 21st century labour market, the calls for interdisciplinarity grow louder and louder. In most cases, engineering graduates are no longer predestined to become part of an exclusive team of highly technical skilled peers but they are more likely to cooperate with colleagues from diverse professional backgrounds. This observation has important consequences for a research project focussing on professional roles of engineering graduates. In some roles, being part of an interdisciplinary team constitutes a fundamental aspect of the content of the role (e.g. project engineer) whereas for other professional roles the interdisciplinary scope is rather limited (e.g. service engineer).

Thirdly, we should look at skills training. Previous research has shown that transversal skills are often not that role-specific [31]. They are needed for each role but with different emphasis. Also the effectiveness of skills training is hardly ever investigated beyond the point of self-assessment by the learners. It remains to be proven that exposure to skills training is effective but proving the gaining of skills is an area that has yet to be investigated.

Finally, of a more philosophical nature, we could debate the prime responsibility for a student's employability. Where does the responsibility of engineering educational institutions stop and where does the student's responsibility takes over? Personal growth and career development are often considered a 'joint venture' between employer (e.g. through providing training opportunities, continuous monitoring of acquired skills/competences…) and employee (e.g. through making use of the offered training schemes, actively reaching out to new opportunities…). For example, Colman and Wilmott [42] showed that 67% of the respondents (N=108) indicate that the development of soft skills for engineering graduates is a joint responsibility for both engineering institutions and students. Only 13% of respondents considered this only to be a responsibility for students. All partners of the PREFER consortium agree that engineering institutions should (1) give a first impetus to students' emerging self-awareness, and (2) contribute to students' empowerment potential aimed towards personal and professional growth.

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