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Graduate Engineering Skills A Literature Review & Call for Rigorous Methodological Approaches

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**Graduate Engineering Skills
A Literature Review
& call for rigorous methodological approaches**

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ABSTRACT

What sort of working world do our engineering graduates face? Engineering has become a global profession, where professional skills are as important as the intellectual prowess gained by obtaining the qualification itself. First, we must consider what skills are needed for engineers to meet the challenges of Industry 4.0. Academics who wish to engage in activities to enhance engineering education might therefore initially seek to identify which skills are most important and there is a wealth of literature addressing different viewpoints which adds further complexity to evaluating such studies.

This paper reports on two independent systematic reviews of literature to identify the most commonly discussed skills that engineering graduates require from the focus of different stakeholders. The first study audited 129 papers and identified the list of most commonly discussed skills, which was then condensed into a list of 17 professional skills. Independently, a review of the lists of skills used in 16 quantitative studies was carried out in relation to engineering skills requirements for graduate engineers specifically.

The results of both studies are compared to highlight the similarities and differences between the results of each method. The work also aims to highlight concerns over providing lists of skills in survey questionnaires without a rigorous research methodology. It is hoped that this paper will generate discussion and aims to raise additional research questions to initiate more in-depth research, into the differing views and contextual relationships of skills' listings.

1 INTRODUCTION

Professional skills, sometimes referred to as generic, soft or transversal skills in the context of this research can be defined as the skills which are valued by employers [1].

A review of literature on skills in engineering was carried out in 2006 which concentrated primarily on publications relating to the UK [2]. The author concluded that rather than clarifying the required skill set for engineering, the extent of literature published by variant organisations merely confused the definition and she concluded that further research is required. Concerns were also raised by Holmes [3] who summarised three problems with using lists of purported skills or attributes in surveys. The first is the provenance of such lists and he highlights that many studies use previously published 'other lists' in their research. He gives examples to show that the 'other lists' may not have been derived from a firm theoretical base, but as they are presented in a form with statistical analysis, it gives the impression of validity. The second is that responses to such surveys must be considered as opinions or perceptions, not facts. For example, whilst some employers may respond that a particular skill is important, it does not necessarily relate to action, i.e., that they use that determination when employing new staff. Finally, Holmes [3] warns against presenting data analysis from such surveys in a statistical form, using means and standard deviations, when there can be considerable variation in the respondent's understanding of the question or meaning.

This paper reports on two systematic reviews of literature carried out by two researchers each working independently, to identify the most commonly discussed skills that engineers require. The reviews were carried out previously as part of other research projects and this paper has resulted from a reflection on those findings, so the intention here is not to replicate the reviews but to compare independent results.

The first study audited 129 papers and identified the list of most commonly discussed skills within those papers, which was then condensed into a list of 17 professional skills. Independently, 139 studies were identified and of those, a review of the lists of skills used in 16 **quantitative** studies was carried out in relation to engineering skills requirements for recent graduates. The frequency of appearance of each skill was counted and aggregated into a final list.

2 METHODOLOGICAL FRAMEWORK – LITERATURE REVIEW 1

Sources for review and the review process itself were identified using a staged process which is described further below. The aim was to adopt a process which can be replicated by other researchers and so an audit trail of decisions made is also provided.

2.1 Inclusion criteria

An initial scoping study led to the decision that a worldwide search be undertaken and all papers, conference proceedings, governmental and employer body publications be considered. The aim was to include as many stakeholder opinions as possible.

The final search terms were “engineering” OR “engineer” AND “graduate attributes” OR “employability skills” OR “generic skills” OR “key skills” OR “core skills” OR “life skills” OR “essential skills” OR “key competencies” OR “graduate qualities” OR “graduate capabilities” OR “generic attributes” OR “soft skills” OR “personal attributes” OR “Employability” OR “professional competencies” OR “workplace skills” OR “work readiness” OR “professional practice” OR “transferable skills” OR “personal skills”.

The selection of databases included; Academic Search Complete, ERIC, British Education Index, Australian Education Index, Science Direct. Furthermore, searches were undertaken to include the publications of the Royal Academy of Engineering, The Institution of Civil Engineers, The Institution of Structural Engineers, the National Academy of Engineering and SEFI conference papers in 2015 and 2016. The initial search yielded 129 papers and this was considered sufficient for this study and therefore, the literature cited by the studies was not investigated further.

2.2 Filtering

Figure 1 provides a representation of the filtering process for the papers in study 1. Initially, each paper was screened to confirm that it related to both engineering and skills in the broadest sense. Twenty-three papers were excluded as the focus was on generic skills not specifically relating to engineering. A further eleven papers were excluded because whilst they did refer to engineering and skills there was no mention of specific skills requirements which was the purpose of this exercise. In total, 97 papers were included within the study, of which 72 papers were journal or research papers and 25 were publications from industry or government/ institutional organisations.

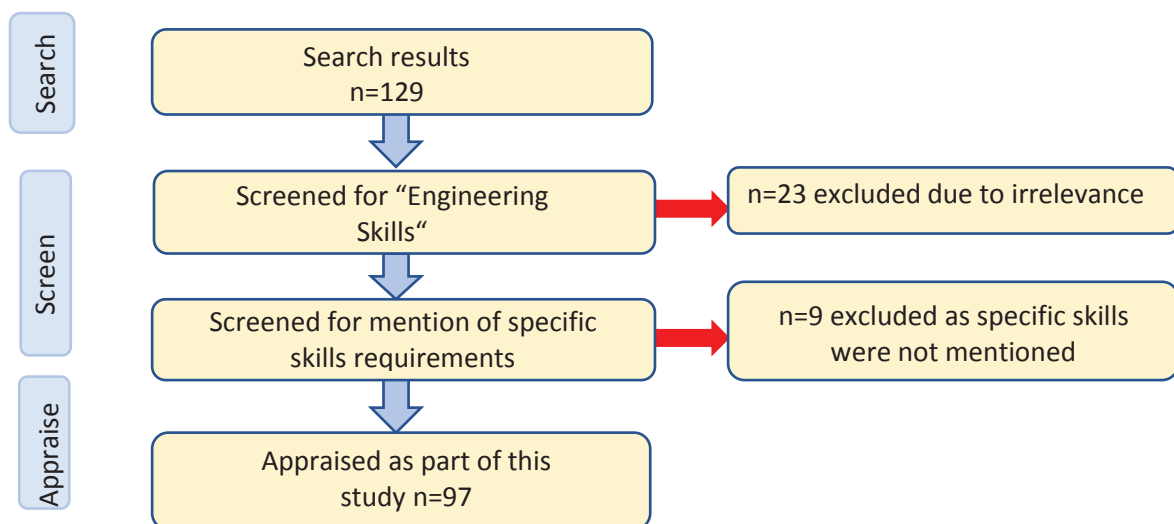


Fig. 1. Flowchart of filtering process using in Literature Review 1

3 CODING AND ANALYSIS - LITERATURE REVIEW 1

The purpose of this study was initially to identify those engineering skills which were most discussed in papers produced between 2009 -2016 with a view to creating a list of skills for use in a follow up survey. Whilst the analysis of the data did not seek at this stage to produce qualitative findings, the coding process drew upon the General Inductive Analysis methodology as defined by Thomas [4]. This first phase of analysis 'open coding' resulted in 66 non-hierarchical categories, supported by definitions and inclusion criteria. In this analysis, the themes identified were not grouped into predefined categories, rather through a process of inductive reasoning, salient categories of meaning were derived from the data.

Each paper was analysed methodically and each mention of a specific skill was coded. The context in which a skill was mentioned was not considered. For example, both “However such teaching methods [...] do nothing to develop transferable skills such as team working, communication skills or the ability to think ‘outside the box’” [5, p.20] and “These students do not value the course’s use of presentations in the development of their communication skills” [6, p. 212] were both coded under ‘Communication’ and the Bourn & Neal [5] citation under “Teamwork “ too.

At this initial stage of coding an interpretative analysis was used. For example, both “...suggests that we need to pay greater explicit attention to such personal skills, and more generally to emotional intelligence within our curriculum” [7, p. 41] and a table which included graduate perceptions of their competencies which included “socioemotional” [8, p. 3787] were both coded under ‘Emotional Intelligence’. In phase two, each of the 66 the categories were reviewed, refined, distilled, re-labeled and merged which resulted in 17 overall categories describing the skill set, which are displayed in Table 1 later in this paper.

4 METHODOLOGICAL FRAMEWORK – LITERATURE REVIEW 2

Both conference and journal publications were included in this study, while magazine articles and other such literature were omitted due to a lack of a peer review process. The goal was to identify the most commonly mentioned skills with reference to **graduate engineers**. In particular the focus was on the rational approach to the identification of these skills and so literature containing quantitative data was sought out such that only research papers containing ranked lists of skills were considered.

4.1 Inclusion Criteria

The initial search terms used were “engineering skills” AND “engineering competences” anywhere in the text, this proved to be an unmanageable amount of literature and so the search terms were narrowed to “graduate engineering skills” and “graduate engineering competences” searching in the title of the paper. This led to the identification of 138 journal and conference papers between 2000 and 2017.

The year of publication was chosen to start at 2000 due to the introduction of the ABET criteria, it is the authors view that the introduction of ABET has had a significant contribution to the volume of literature published in the area of professional skills since it’s inception.

4.2 Filtering

Papers which did not contain quantitative data were excluded, along with papers which did not concern themselves with graduate skills or competences. This led to the appraisal of 4 conference papers and 12 journal papers for this study. The databases included; Wiley, Taylor & Francis and ASEE Peer. The process of searching, screening and appraisal is illustrated in Figure 2.

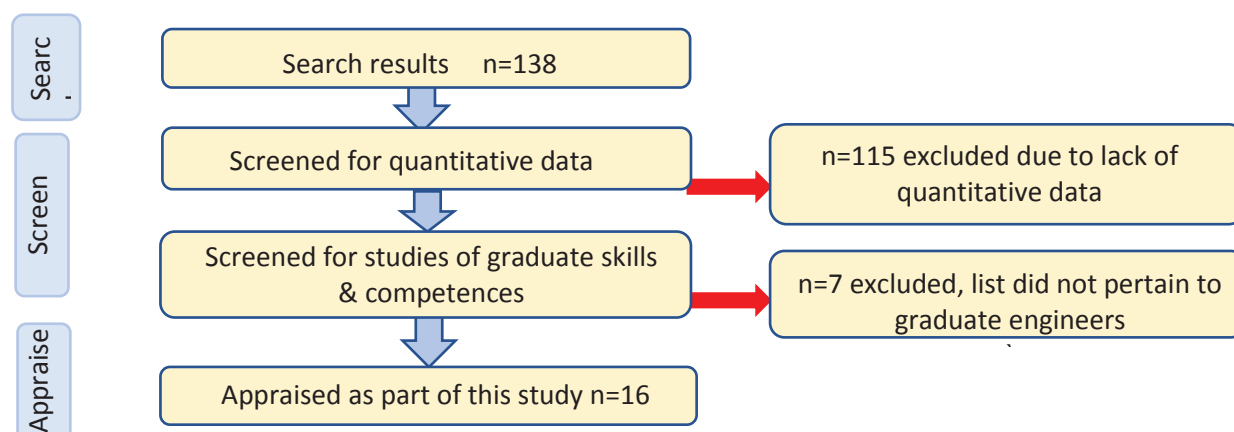


Fig. 2. Flowchart of filtering process using in Literature Review 2

5 CODING AND ANALYSIS - LITERATURE REVIEW 2

Papers containing ordered lists of skills which were either ranked or rated were extracted and aggregated into a final list of skills based on the frequency of use of each term and categorised using the European Skills Competences and Occupations (ESCO) [9] framework as a guideline. There are huge methodological assumptions being made to carry out this analysis, including that when an author refers to *teamwork* in one paper, that *teamwork* means the same thing in subsequent papers and so can be aggregated together. This is difficult to extract, given that in 16 papers, only 11 provide definitions of the skills they are referring to and only 9 made reference to the framework upon which the definitions were created. The other assumption is that these skills are culturally invariant, a more in-depth analysis would attempt to address socio-cultural differences in lists of skills.

6 RESULTS AND DISCUSSION

Both studies aimed to identify the list of skills which were most commonly mentioned in each systematic review. *Table 1* shows the most commonly mentioned skills in each Literature Review according to the frequency that each identified skill was mentioned.

Table 1. High level categories in rank order for the frequency of mentions.

Literature Review 1		Literature Review 2	
Skill	Frequency	Skill	Frequency
Character and Interpersonal Skills	433	Communication	29
Teamwork/Groupwork /Collaboration	249	Teamwork & Collaboration	18
Communication	195	Problem solving	18
Technical skills	189	Technical skills	16
Problem solving	130	Business/finance/entrepreneurship	16
Business Acumen	111	Planning & organising	16
Globalisation, Intercultural Skills	93	Ethics and sustainability	12
Self-Directed Learning/Independence	84	Cultural awareness	11
Project Mgmt/Planning/Organisation	67	Lifelong learning	10
Leadership	54	Professionalism	8
Practical application/Real life problem	37	Project management	8

Critical thinking	36	Social and political awareness	8
Research skills	31	Knowledge science, engineering	7
Foreign Language skills	19	Design	7
Risk Management	10	Interpersonal skills	5
General Knowledge	10	Leadership	5
Health and Safety	8		

6.1 Similarities and differences

The purpose of this paper was to compare two independent skills lists. At first glance, it is clear that skills such as Communication, Teamwork, Problem Solving, Technical Skills and Business are all highly cited and since both researchers used independent interpretive techniques, this suggests there is general agreement on these terms.

However, the differences in the two lists present a more interesting finding, and two examples are presented here; Character and Interpersonal Skills and Business Acumen.

6.2 Character and Interpersonal skills

In the first list, this was interpreted as having the highest number of mentions, whereas in Literature Review 2, this skill was located near the bottom, with only 5 mentions. As each researcher interpreted this differently, it led us to a discussion on what we mean as Character and Interpersonal skills. *Table 2* presents the subthemes which were coded within this category for both literature review 1 and 2.

Table 2. Sub themes allocated to the Character and Interpersonal Skills category in rank order for frequency of mentions.

Literature Review 1		Literature Review 2	
Character and Interpersonal Skills	Frequency	Interpersonal skills	Frequency
Ethics or Integrity	68	Interpersonal	2
Creativity or Innovation	67	Interpersonal skill	1
Social Responsibility	56	Personability	1
Sustainability or Environmental awareness	44	Personal quality	1
Adaptability/Change Management	32		
Emotional Intelligence	22		
Attitude to work	19		
Self discipline	12		
Self reflection and analysis	12		
Enthusiasm Motivation Curiosity	11		
Professionalism	11		
Decision Making	11		
Grit/Determination/Perseverance/Commitment	6		
Confidence	6		
Taking responsibility/Ownership/Accountability	3		
Self Awareness	3		
Work under pressure	2		
Maturity	2		

Here we can see differences in how each researcher interpreted each skills list. For example, ethics and integrity is included within Character and Interpersonal Skills in review 1, whereas it is pulled out as a separate skill under Review 2 and combined

with Sustainability, which is included as another sub theme in Review 1. This raises the question; does each researcher conceptualise “ethics” as the same thing. In Review 1, it is aligned with integrity, suggesting personal ethics, internal to a person, yet in Review 2 aligned with sustainability, it suggests a relationship with the environment and society, the outside world. Professionalism is another example of where one researcher includes it as a sub theme of a larger conception, but another interprets it as a skill within itself.

6.3 Business Acumen

As an alternative example, *Table 3* shows the subthemes associated with Business Acumen and Business, Finance & Entrepreneurship.

Table 3. Sub themes in the Business category in rank order for number of sources.

Literature Review 1		Literature Review 2	
Business Acumen	Frequency	Business Finance and Entrepreneurship	Frequency
Entrepreneurship	23	Business & finance skills	5
Finance and Economics	19	Business skills	3
Customer Needs	13	Negotiation	3
Business etiquette	1	Entrepreneurship	2
		Finance	1
		Cost management	1
		Bargaining	1

The results of this analysis show that similar terms are included in both reviews, but in this instance, Literature Review 1 was much more confining in the terms associated with Business Acumen, than Business, Finance and Entrepreneurship in Review 2. Here, Review 1, defining the theme as Business Acumen, does not give justice to the expanse of the terms within the theme itself. It was not obvious that entrepreneurship was included within this category. This highlights the importance of accurate naming each skill taking cognisance of the range of terms within.

Here again, is another example of a difference in conception of a particular term. Negotiation, included here under Business, Finance and Entrepreneurship in Review 2 was also identified as a subtheme in Literature Review 1, but under the theme “Teamwork, Groupwork, Collaboration”. Researcher 1 understands negotiation to be about people, changing people’s minds, working with people to find a solution, whereas negotiation according to Researcher 2 is a business skill that can be learned.

The purpose here is not to suggest that one is more correct than the other, but to show the varying conceptions that researchers can have when creating lists of skills.

6.4 Conclusion

This paper came about from a discussion between two independent researchers who had undertaken literature reviews on skills listings for different purposes. When comparing these skills listings, it became apparent that both researchers had differing views on the conceptions of certain skills and this led us to write this paper to highlight our findings to other researchers.

This paper aimed to investigate the validity of using lists of skills in questionnaires and surveys. The results show, that whilst there may be some general agreement on some

terms, there are also differences in how different researchers interpret those terms. As a result, using lists of skills in surveys adds an additional layer of complexity, as it is not only the researcher writing the list that interprets, but the survey participant too. This leads us to a call for more interpretive rigorous approaches to the use of skills lists in research studies.

We suggest that instead of using predefined lists of skills' terms in quantitative surveys, that each researcher takes the time to review the different conceptions of each term and that a description of the researchers understanding of the term is provided, to reduce the risk of a misunderstanding by any survey participant. The researchers involved in this comparative study have found it invaluable to discuss the different conceptions of some of these terms with someone with a different background and viewpoint and are now left with a more critical outlook on the use of lists of skills in quantitative surveys.

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